The Maize Value Chain in Zambia: Dynamics and Resilience Towards Production Shocks

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[1] This paper is based on a more extensive master thesis by the same author. To request more details concerning the work, please email: *Conrad.Steinhilber@gmx.de*

Abstract

Zambia is a country whose food security largely depends on maize. In the light of expected structural maize deficits and the likely occurrence of shock events, the aim of this paper is to test the resilience of the Zambian maize value chain towards production shocks in terms of food supply security, and to find policy recommendations on how to increase this resilience. To that end, I devised and applied a new framework for measuring resilience properties using System Dynamics, which relies on comparing the development of food security indicators between the base run and the respective shock scenario run of a simulation model. Results show that the value chain is quite resilient towards floods and exchange rate shocks, moderately vulnerable towards changes in fertilizer subsidy programmes, and very vulnerable towards droughts, especially prolonged ones. In general, the resilience of the value chain towards one-time shocks is good due to the existence of maize buffer stocks that people can consume when production is low. However, the value chain is not very resilient if faced with two or more different shocks, as buffer stocks are quickly depleted and maize demand cannot be serviced any more. The resilience properties are also strongly affected by demand adjustments of consumers in response to changing maize availability, and moderately affected by the distribution of maize in between the informal and formal value chain and the storage policies of FRA. The observed resilience properties can endogenously be improved using smart long-term maize storage policies that exploit surplus production years.

1. Introduction

1.1 Overview

Zambia is a society built on maize. Since the colonial period, a large part of the government's legitimacy has depended on its ability to fulfil the implicit social contract with its constituency that requires it to ensure a sufficient maize supply for the population (Jayne & Jones, 1997). And the importance of maize has not waned over the last decades: even today, maize still accounts for over 50% of the calories consumed by an average Zambian citizen (FAO, 2015b), whereby especially the poorest strata of society depend on maize over-proportionally (Nicole Mason & Jayne, 2009). This might not be a problem per say would Zambians live in a state of food security – but unfortunately, the opposite is true. FAO's (2014b) food security indicators show that Zambia has only been able to supply around 90% of the calories its citizens need to live a healthy and active life over the last years; and Gerber (2015) expects a structural maize deficit to emerge in Zambia in the near future. On top of this generally tense situation, weak political and economic institutions, bad infrastructure, heavy reliance on one main staple food crop and high exposition to sudden and strong changes in its climatic, political and economic environment leave Zambia in in a position of high vulnerability on many levels (Bertelsmann Transformation Index, 2012; Stockholm Resilience Centre, 2012; UNDP, 2014).

Given the central role of maize in Zambia, the population's access to maize can legitimately be seen as a proxy for overall food security in Zambia. Furthermore, several sources suggest that the generally weak political and economic institutions, poor infrastructure, heavy reliance on one main staple food crop and an exposition to sudden and strong changes in its climatic, political and economic environment, that it shares with most of its Sub-Saharan African neighbours, leave Zambia in in a position of high vulnerability on many levels (Bertelsmann Transformation Index, 2012; Stockholm Resilience Centre, 2012; UNDP, 2014) . I will therefore adopt a resilience perspective and explore what happens to the maize supply in Zambia when it is faced with production shocks. I want to find out how resilient the mechanisms that bring the maize "from farm to fork", i.e. the maize value chain, are towards production shocks – and what can be done within the political and economic boundaries of Zambia to enhance those resilience properties.

To that end, I will devise a framework that enables the quantitative measurement of resilience with a System Dynamics (SD) simulation model. The completion of this case study will also serve as a test of the usefulness and feasibility of the resilience framework devised, and contributes to resilience research at large by exploring the usefulness and applicability of the concept for specific case studies (Janssen & Anderies, 2013).

1.2 Problem Background

To get a clearer picture of the food security situation in Zambia, it is useful to look at FAO's indicators. The Prevalence of Undernourishment (PoU), denoting the probability that a randomly selected individual from the reference population consumes less than her calorie requirement for an active, healthy life was as high as 48.3% for the last measurement period of 2012-13 (FAO, 2014). This means that every second Zambian you would meet by chance is undernourished – a clear sign that food security is still a big issue in Zambia.

But in how far is this lack of food security attributable to availability problems? Looking at the ADESA, we see that it has been fluctuating around 90% in the last years, meaning Zambia could only supply 90% of the calories that its citizens need for a healthy lifestyle. Moreover, Gerber (2015) expects that Zambia will enter a structural maize deficit in the near future due to stagnating harvests and growing population, making the supply situation even worse than it has been in the relatively good last harvest years.

Hence, we can conclude that food insecurity is an on-going problem in Zambia, that not only stems from an inefficient distribution of food in the society (*access* dimension), but also from the fact that the most basic requirement of sufficient *availability* of food is not fulfilled. Following the rule that the most basic problems need to be addressed first, my work will therefore focus on the problems of availability of food in Zambia.

However, since modelling all the value chains for all crops consumed in Zambia is not feasible, it makes sense to find a proxy for food security. The obvious choice for this is maize, since the long history of strong government support for maize (Zulu, Jayne, & Beaver, 2007), coupled with deeply rooted cultural perceptions and traditions, made and sustained maize as the single overwhelmingly important staple food crop in Zambia. Even in spite of recent shifts towards a greater crop variety, maize still accounts for over 50% of calories consumed in Zambia as of 2011 (FAO, 2015b) and is cultivated by 80% of farmers in Zambia (Zulu et al., 2007).

Furthermore, Mason & Jayne, (2009) have found that there is a strong correlation in Zambia between low income and an above-average reliance on maize as the main source of calorific supply. This means that especially the poorest, who are typically also the most vulnerable to shocks of all kinds, depend on maize over-proportionally for satisfying their basic calorific needs. As food insecurity is mainly a problem for the poorest strata of society, this means that maize is especially important to maintain food security for all of the population in Zambia.

From the above information, it becomes clear that there can be no adequate food supply for Zambians at large without a sufficient supply of maize. Since the value chain represents the very mechanisms that actually get the maize from the farms scattered around the country's remote places to the non-subsistence consumers in the (semi-) urbanized regions, it's role is obviously decisive: no distribution of food from producers to consumers can take place without a functioning value chain.

Field research suggests that food value chains are crucial when trying to address inadequate availability of food, as in Sub-Saharan Africa, post-harvest losses typically number around 10-23% of the original production (Hodges & Bernard, 2014). Bou Schreiber (2015) shows that this problem is especially pervasive in Zambia: the main maize purchaser FRA (Food Reserve Agency) uses mostly inadequate storage facilities, leading to heavy annual grain losses that become even worse when the system is shocked out of its equilibrium state, e.g. by unexpected bumper harvests.

2. Methodological Framework

Resilience is a very broad topic that has received increasing attention in various disciplines over the last years. Yet, the use in manifold contexts and relative novelty of the concept contributes to a lack of conceptual clarity and the existence of many different competing definitions of resilience (Carpenter & Brock, 2008; Henry & Emmanuel Ramirez-Marquez, 2012). However, the concept is of course not used completely arbitrarily and therefore does have a certain core that is widely agreed upon. Olsson, Jerneck, Thoren, Persson, & O'Byrne (2015: p. 1) define this core as the agreement that *"resilience is concerned with the ability* [of a system] *to cope with stress or, more precisely, to return to some form of normal condition after a period of stress."*

In their endeavour to further clarify the nature of resilience discourses, Olsson et al. (2015) reviewed the systems thinking literature and concluded that there are essentially two types of definitions of resilience in use:

1. **Resilience as "bouncing back"**
   This definition stresses the quality of a system to withstand a disturbance and to recover from it, while preserving its structure. Insofar, resilience is seen as the ability of a system to resist forced structural change, while maintaining and/or recovering its central functions. (See also: Dalziell & Mcmanus, 2004)

2. **Resilience as "bouncing back and transforming"**
   This definition, contrary to the first one, understands the resilience of a system as depending on the ability to change its structure. The idea is that when a system is faced with a disturbance, it not only bounces back by recovering important functions, but also transforms its structure in a way that makes it better adapted to cope with the new environment.

These two lines of thought are therefore somewhat contradictory in how they view the role of preserving a system's structure. Adopting the second view also creates further questions about the identity of a system: how big can the structural change be, so that the transformed system is still considered a "smart adaptation" of the original system, and when does the change become so big that the system essentially loses its identity and can thus be considered to have broken down and succumbed to the disturbance?

Summing up, we can conclude that there are competing, even partially contradictory, definitions of resilience and none can per se be said to be superior to the others. However, to achieve conceptual clarity in my research, it is imperative to choose a clear definition.

Since I want to find out how the supply of maize changes in relation to production shocks, I will have to look at short-to medium term changes that take place in a set of parameters within a few months to years. It is very unlikely that the basic structure of maize value chain will change significantly within this relatively short time, so that the component of structural change that is central to the second definition is not relevant. As methodology choices should be made according to their usefulness in reaching the research objectives, I will therefore adopt the "bounce back" definition of resilience. "Vulnerability" will denote the absence of resilience, or propensity for high impacts of a shock on a parameter.

However, it remains to make this still rather vague concept measurable. Henry & Emmanuel Ramirez-Marquez (2012) propose a framework that operationalizes resilience as a function of time, which is well suited for application in simulation models. They remark that resilience always has to be understood as resilience *of a certain function in the system against a certain shock event*. This makes sense, as function A of a system might not be affected by a shock, while function B might break down completely – but when faced with a different shock, the system might be able to maintain function B, but not function A.

Henry & Emmanuel Ramirez-Marquez' (2012) framework therefore requires to specify the central functions of a system that one wants to evaluate, which they call "figures of merit" (FOM). The development of these FOM is then simulated in a no-shock base run and a shock scenario. The extent of change in the trajectory of the FOM between the base run and the shock scenario then indicates how resilient the system is in terms of that specific FOM to that specific shock. A graphic representation of this idea can be seen in figure 1.

Henry & Emmanuel Ramirez-Marquez (2012) further differentiate between two features of resilience in their framework:

- The **initial vulnerability** is determined by how strong the initial impact of a system disturbance is on the FOM. In figure 1, this would be the drop in the scenario graphs occurring between times seven and eight. The FOM in scenarios 1 and 2 drops by 6,5 units, while the FOM in scenario 3 only drops by 4,5 units. The initial vulnerability of the FOM against the shock in scenario 3 would thus be smaller.

- The **adaptive capacity** is determined by how fast the FOM recovers from the shock by returning towards its original base run trajectory. The FOM shows the lowest adaptive capacity towards the shock in scenario 1, as it takes the longest time to return to the base run trajectory. While the FOM in shock scenarios 2 an 3 actually rise by a total of 6,5 units throughout the first six time steps after the onset of the shock, the FOM in scenario 1 only grows by 3,8 units in the same time.

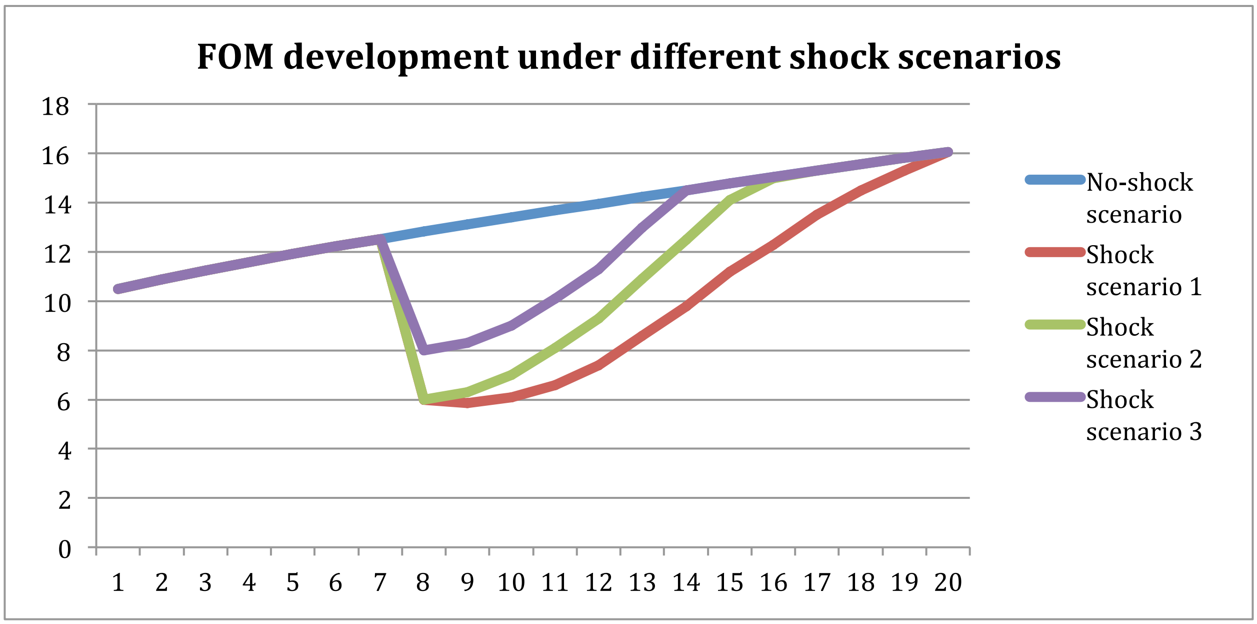

Figure 1:Development of FOM under different shock scenarios

The overall resilience of the system in terms of the FOM under consideration is therefore measured as the integral between the base run and the respective shock scenario run curve of the FOM. This framework will be the basis for measuring resilience in my analysis.

The choice of an FOM for my analysis is guided by the insights we have gained so far: that there is already not enough calorific supply in Zambia to fulfil the population's needs for an active and healthy life, and that maize plays a decisive role in ensuring this supply. With these two guidelines in mind, I created a new indicator that is based on the ADESA and will serve as the central FOM for my resilience analysis. ADESA is an indicator that measures the availability of food (DES) in relation to the demand. While the availability is solely determined by the total amount of maize in the market, and does not account for problems concerning the access dimension, demand is determined by the Average Dietary Energy Requirements (ADER). The ADESA calculated as a ratio using the following equation: $DES/ADER$. So if for example, the demand for food per person is 3000 kcal/day, but only 2000 kcal/day can be consumed due to a lack of availability, the ADESA takes the value of 0,67.

The indicator I intend to use as the FOM for my resilience analysis is called "Adjusted Dietary Energy Supply with Maize" (ADESM). It is a modification of the ADESA in four respects: firstly, since we are just looking at the maize sector it is only concerned with maize instead of all food sources. Secondly, I am looking at the population of Zambia as a whole and therefore aggregate all individuals' ADER to one national demand. Thirdly, my model includes feedback loops that alter demand as a result of changes in availability. The demand in the model is thus adjusted to represent parts of the access dimension as well. Fourthly, the availability of maize (equivalent to the DES) is measured in terms of consumption. This rests on the simple and plausible assumption that consumers will consume whatever amount they demand when that maize is available to them.

Like the ADESA, the ADESM is measured as a ratio between zero and one, with a value of one representing a full servicing of the adjusted demand, and zero indicating that no consumption takes place at all. Hence, the ADESM is calculated using the following formula:

$$ADESM = \frac{Maize\ consumption}{Adjusted\ demand\ for\ maize}$$

3. The Model

3.1 Scope

Kaplinsky & Morris (2001: p. 4) define a value chain as *„the full range of activities which are required to bring a product or service (...) through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use"*. In the case of maize meal, it makes sense to focus on maize, as it is the central raw material required to produce maize meal (along with the labour and capital needed to refine it). I thus define the start of the value chain as being the production of raw maize by farmers in Zambia. Adopting this product-based view makes it clear that the end of the value chain then has to be the consumption of the maize meal by consumers.

The length of the simulation is from 2004 to 2020, with 2004 - 2014 being the reference data period. Furthermore, it is important that the model runs in months in order to be able to reflect the strong seasonality of the Zambian maize market: the green harvest comes in in March and April, followed by the main harvest in May and June. While private buyers start purchasing maize from smallholder farmers right away when the harvest becomes available, FRA only purchases maize in the official government-announced marketing season, which usually lasts from June/July until the end of September or beginning of October (Nyanga, 2015b). While maize is usually well available in the months following the harvest (the "plenty season"), supplies dry up later in the year (Jayne et al. 2009). This happens either because the harvest was too small to service domestic demand, or because large FRA purchases have locked up all the remaining maize in the formal value chain, so that consumers in the informal chain are devoid of supply. The time following the harvest (roughly April – October) is therefore called the "plenty season", while the time later in the marketing year (roughly November – March) is seen as the "lean season".

Since my aim is to understand the dynamics of the maize value chain in Zambia, it seems trivial to say that the geographical boundary of my analysis will be Zambia as a political, economic and geographic entity. However, this has important implications for the model. While export and import decisions are made and financed according to internal dynamics, and are thus represented in the model, food aid is administered by external agents and thus not portrayed. This is because food aid constitutes a transfer of goods from other geographical areas and political entities that is ultimately at donor discretion and cannot be influenced by actors from Zambia. Since the aim is to find out what the resilience properties of the maize value chain *in Zambia* are, and what can be done in Zambia to enhance those, looking at food aid does not help answering the question and is thus excluded.

3.2 Model Overview

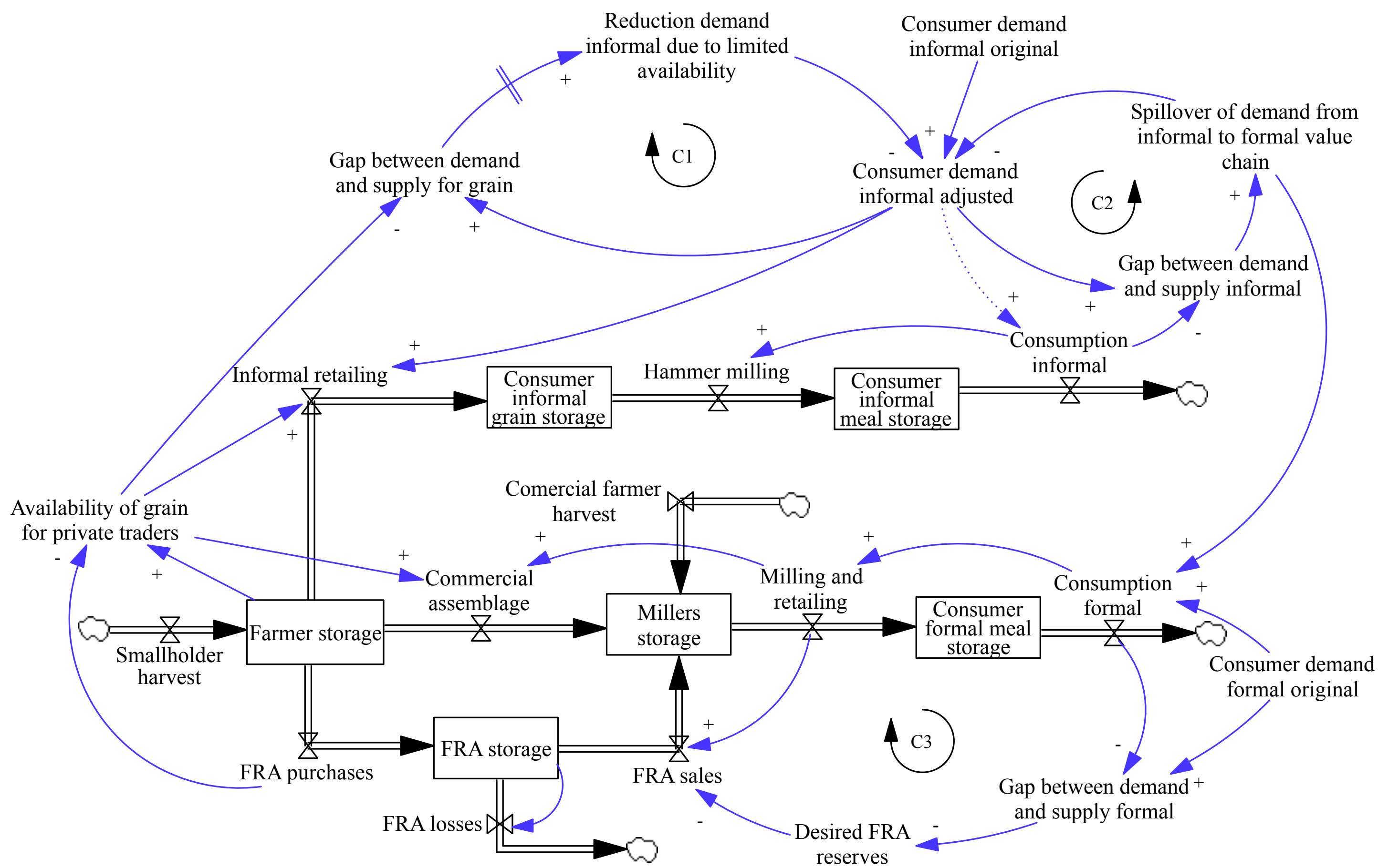

Figure 2: Value chain model overview

The value chain begins with the production of maize by smallholder farmers. They store their maize in the form of grain and then sell it (often via assemblers acting as middlemen) to either informal grain retailers, commercial millers, or the FRA. Since FRA usually buys at above-market prices (N. M. Mason & Myers, 2011), I assume that farmers prefer to sell to them and reserve as much grain as possible for FRA sales – only the remainder is sold to private buyers.

From there, the maize value chain is effectively split in two: there is the more formalized avenue (which I will call **formal value chain** henceforth) shown at the bottom in figure 2, involving farmers selling either directly or through small-scale assemblers to large commercial millers, these millers milling and refining the grain to different types of meal, selling it to retailers and these retailers then selling their bags of maize meal to consumers, who finally consume the product. The FRA is also involved in this avenue, as it purchases large amounts of grain from farmers, then selling it only to large commercial millers later in the year (N. M. Mason & Myers, 2011).

Note that commercial farmers, who in recent years accounted for about only 8% of the production (see appendix C.3), just like FRA, only sell to larger commercial millers in the formal value chain, and not to small-scale informal grain retailers or consumers. Since retailing takes maximally only a few days and retailers have not been observed to exhibit significant strategic behaviour, I subsumed retailing into one flow with milling (which is also done quickly in comparison to the time step of a month). A developed wholesale sector is generally lacking and therefore also not represented in the model(Nyanga, 2015a).

However, there is also the less formalized avenue visible at the top of figure 2 (henceforth the **informal value chain**), which is formed by consumers buying grain directly from farmers (in rural settings), or from informal grain retailers that purchase grain from small maize assemblers or farmers. These consumers then bring their grain to small hammer mills throughout the country to transform it into whole grain maize meal, which is then taken home and eventually consumed by themselves (Leathers, 1999: chapter 5). Here as well, a developed wholesale sector is missing.

Both of these chains work like a classical supply chain with a backwards-induced feedback structure, so that downstream demand drives upstream demand. Upstream actors not only adjust their orders according to changing demand from downstream consumers, but also adapt their inventory upwards (according to: coverage time * orders) to be able to cover a longer timespan of orders with the new higher volume from their inventory. The structure is thus prone to produce a bullwhip effect when changes in demand occur, as increases in demand are amplified with every upstream stage.

There are three main feedback loops in the model. The first one (C1) alters informal demand in response to availability. The counteracting loop C1 represents how informal consumers adjust their demand downwards in times of limited availability, and ensuing high prices for maize. Note that this downward adjustment is limited by a lower bound that corresponds to the minimum dietary energy requirements by FAO (2014): people would take any measures to prevent going below this threshold that means starving.

Loop C2 shows that, when not enough maize is available in the informal value chain to satisfy even the adjusted lower demand, the informal consumers will have to resort to buying the more expensive roller meal from the formal value chain: this reduces demand in the informal value chain and increases demand in the formal value chain. Furthermore, a certain fraction of consumers starts buying other carbohydrates as maize substitutes when maize grain becomes unavailable. This spill over of demand happens progressively stronger in the lean season as grain in the informal value chain becomes scarcer; and the process leads to fluctuations and an ensuing bullwhip effect in the formal value chain. When maize becomes available in the informal value chain again with the next harvest, the demand returns to the level of the original informal demand.

The link between the informal customer demand and the consumption is only represented as a dotted line because the consumption only depends on the demand in terms of its upper bound. However, the gap between demand and consumption is actually is caused by the lack of maize supply coming through the flows from upstream. The loop involving this link is therefore not really a reinforcing loop and I thus did not label it accordingly.

Loop C3 represents FRA's policy to release its reserves when there is a supply shortage in the formal value chain in order to stabilize prices and supply. The feedback from FRA sales to consumption is implicit in the flow structure bringing the maize from the FRA to consumers – the more maize FRA releases; the more is of course available to consumers in the long run for consumption. Note, however, that this feedback loop is limited by the amount of FRA's reserves – once they have released everything in their storage, the loop cannot unfold any more impact.

I further want to draw attention to the importance of FRA's purchasing decisions for the behaviour of the value chain. The more maize FRA purchases, the fewer maize is available for private traders to buy from smallholder farmers – and the fewer they can buy, the smaller becomes the supply with maize for the informal value chain. This again has effects on when loops C1 and C3 become active.

3.3 Assumptions

Since any model is an abstraction of reality, it always has to rely on a set of assumptions that allow a simplification of the real world's complexity, and my model is no exception. The most important assumptions are therefore listed below.

Prices

Since information about prices was not available in sufficient detail and quality, the impact of prices is represented indirectly through preferences of consumers or producers to buy/sell from certain actors that have consistently cheaper/higher prices, or through loop C1 where scarcity acts as a proxy for price development

Post-harvest losses

Losses of maize in the value chain were only modelled if they exceed a certain significance level, which is again determined by the duration and quality of storage. Losses are most significant in FRA storages, where up to 50% of stored maize can be lost due to inappropriate storage per year (Bou Schreiber, 2015).

Exports

Maize exports through FRA are often driven by strongly discretionary political decisions rather than market dynamics, and are thus represented as external. Furthermore, I assume that only big commercial farmers and FRA have the means to export and market their maize abroad. However, the government is assumed to only allow exports in years where domestic maize production significantly exceeds demand.

Imports

I assume that private maize imports are negligible, as they are generally discouraged and hindered through discretionary government interventions, inefficient bureaucratic processes and the fear of having to compete with subsidized FRA maize on the domestic market (Dorosh, Dradri, & Haggblade, 2009). In my model, all imports thus run through FRA, which is the agency charged with carrying out external maize trade operations for the government.

FRA stock management

In order to fulfil its mandate to guard against price fluctuations by keeping maize buffer stocks, FRA is assumed to try to accumulate carryover stocks of maize every year. However, in years of structural maize deficits, they will always release those stocks to stabilize the maize market and support the consumers as much as necessary.

Capacity constraints

The model does not feature capacity constraints since even in years with extreme bumper harvests (such as 2014) and ensuing high volumes of maize handled, no capacity problems have been observed.

Consumer behaviour in the formal value chain

Consumers in the formal value chain generally belong to the wealthier strata of society and are thus assumed to be able to pay higher prices, as maize gets scarcer later in the year. Furthermore, it has been observed that maize prices in the formal value chain are not very elastic towards changes in availability (Nicole Mason & Jayne, 2009). Therefore, I assume that consumption patterns do not change in relation to changes in maize supply.

3.4 Subsistence Sector

Subsistence production is maize that is produced and then consumed by the producing farmers themselves. It never enters the market and the value chain and is thus not relevant for my analysis. However, subsistence production is still important for my model insofar it satisfies a certain share of national demand. Fluctuations in the subsistence demand thus simply mean for my model that those 75% of smallholders who produce mainly for subsistence (Zulu et al., 2007) were able to satisfy their own demand for maize to a greater or lesser degree than in the previous year. Corollary, their need to top up their own maize stocks with externally purchased maize just becomes lower or higher by the same amount that subsistence production fluctuates. The subsistence production is thus simply deducted from total demand (including a mark-down for losses occurring in storage and milling) to yield the demand for marketed maize.

3.5 External Inputs

Concerning the external inputs to my model, the reference period 2004 – 2014 was based on data, while for the development from 2015 – 2020, the following assumptions were made.

Population

Zambia's population is expected to grow steadily and strongly over the next years (UNDESA, 2012), leading to parallel increases in demand for maize.

Maize production

The data for the base run of my model comes from the base run of Gerber's (2015) production model. While he only splits his data in "sold" and "not sold" (i.e. subsistence) production, I further distinguish between sold production from smallholders and commercial farmers. To this end, I assume that the relation of 8% commercial and 92% smallholder production of the total sold production

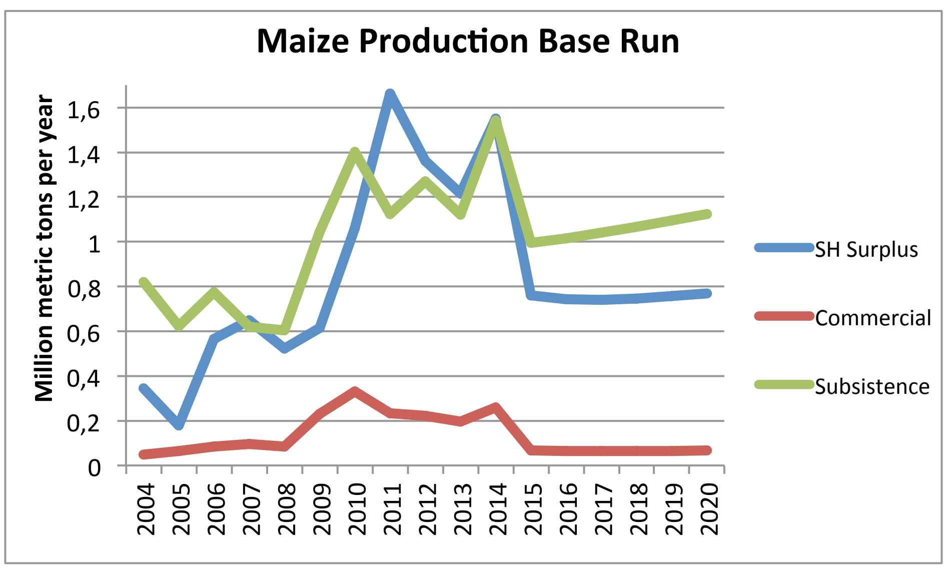

Figure 3: Maize production inputs from data and Gerber's base run

will stay constant for the next years. The development of the resulting yearly maize production that is fed into my model can be seen in figure 3.

Maize imports

For simplicity, and because I am interested in the endogenous development of the maize sector in Zambia without external influences, I assume that the trend of the last three years holds and no maize is imported.

FRA storage capacity

According to Bou Schreiber (2015), FRA plans to heavily invest in increasing storage capacity, so that FRA expects to have 250.000 tons of silo and 1.200.000 tons of shed capacity by 2020.

FRA purchase policy

In order to save money and prevent high storage losses, I assume that FRA scales back on their heavy purchase volume from 2010 – 2014 and regress towards the historical mean of buying around 15% of the yearly traded harvest.

3.6 Validation

Even thought the lack of a reference mode of behaviour graph made it impossible to compare the model's output against it, high confidence in the model was established by subjecting it to a series of tests, as proposed by Barlas (1996). It passed structure and parameter confirmation tests, dimensional consistency test, direct extreme condition test, behaviour sensitivity test, qualitative features analysis, extreme condition test and integration error tests. For the sake of keeping the paper short, I will not go into detail about this, for more information feel free to contact the author.

4. Results

4.1 Base Run Behaviour

An analysis of the behaviour of the base run should be based on the evaluation of the behaviour of the central variable, which is the ADESM. Since the model runs in months from January 2004 on, the time units on the graphs should be understood in the following way: month 1 is the beginning (January) of 2004, month 2 is February 2004, month 13 is January 2005… and so forth up to month 204, which is December 2020.

The graphs showing the ADESM always display a value range between 0 and 1.

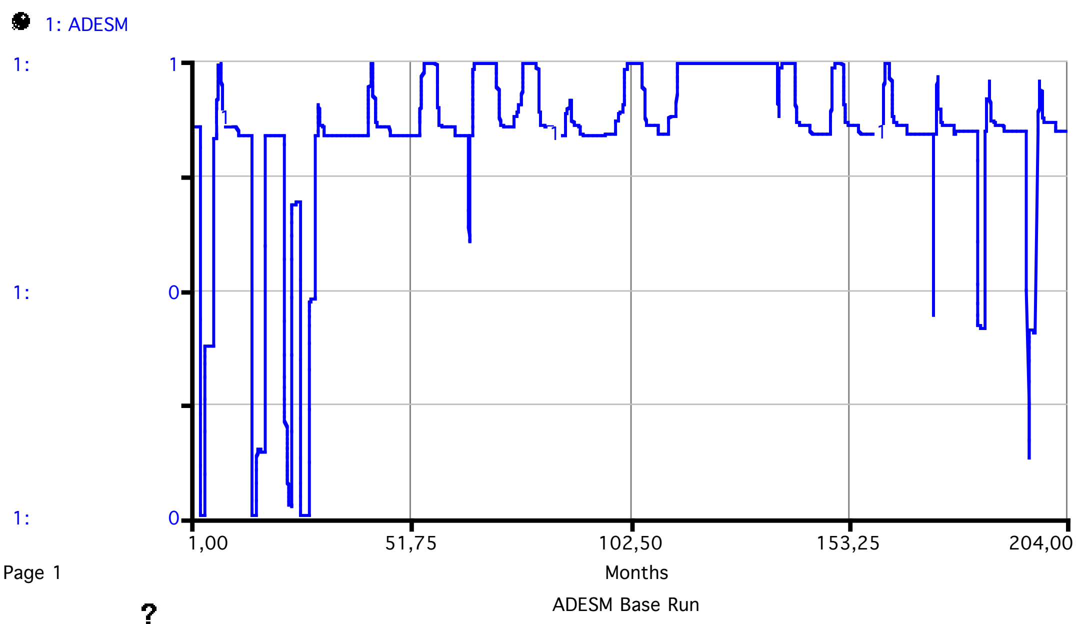

Figure 4: Behaviour of ADESM in base run

The first thing that you will notice when looking a the ADESM's behaviour in figure 4 is the strong seasonality: every year, with the exception of summer 2013 to summer 2015 (months 112-136), the ADESM fluctuates throughout the year. That has to do with the seasonality of the maize harvest: while there is some green harvest coming in every year in March and April, it only has a share of 7.5% of the total production. The main harvest then becomes available in May and June, which is when you see the ADESM spiking up. This behaviour reflects the typical alternation between the "plenty season" and "lean season" in Zambia (Nicole Mason & Jayne, 2009), where maize is well available in the months following the harvest and becoming very scarce in the months at the end of the marketing year. Since the first and last years of the simulation are years of structural maize deficit, the domestic maize consumption is used up after a few months following the harvest and the ADESM thus drops to zero. Note that Zambia did receive food aid in those years that most probably prevented the maize supply from completely drying up, but since we are focusing on the internal dynamics of maize production these are neglected, as discussed in section 3.1.

The increasing size of the drops in the ADESM in the lean seasons of 2018-2020 (months 169-204) is because Zambia experiences a roughly steady yearly production from 2015 on, while the population gradually grows. The gap between production and demand therefore becomes increasingly bigger.

A little exception to that general seasonality pattern is the smaller spike that the ADESM shows from zero to about 0,6 in the months 23-24 (November-December 2005). This is due to the incoming harvest by commercial farmers that I assume to start selling in the height of the lean season in order to receive better prices. However, as their share of the total traded production drops over the following years, the impact of their production on the ADESM declines as well.

The reader will further notice that the ADESM often stagnates at a level of 0,84. This happens when the supply of maize grain for consumers in the informal value chain has dried up, making them lower their consumption and eventually start purchasing commercial roller meal from the formal value chain. The fact that this behaviour occurs even in years of surplus production, such as 2010-12 (months 73-96), is due to dysfunctional FRA policies.

A good year to explain the dynamics behind this phenomenon is 2010 (months 73-84): while this year actually features a good harvest that exceeds demand by a great margin, FRA purchases such vast amounts of maize (878.750 tons out of the total yearly smallholder production of 1.062.010 tons), that not much is left to purchase for private buyers. Millers, via small commercial maize assemblers, and informal grain retailers then compete for this relatively small amount of maize grain available to private buyers. Thus, their demand cannot be satisfied, which ultimately leads to supply shortages in the informal value chain.

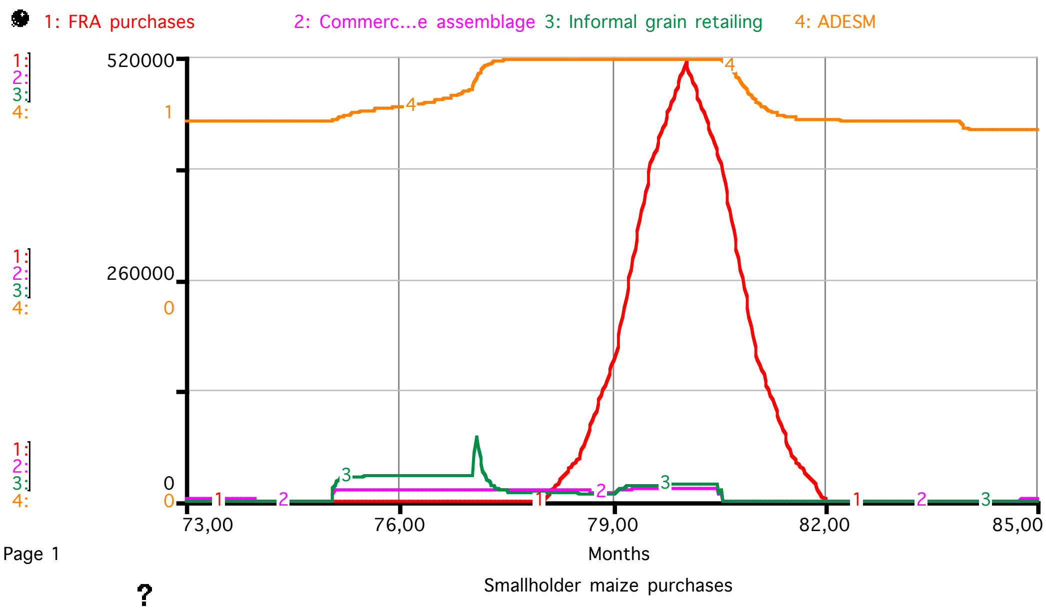

Figure 5: Smallholder grain sales

In figure 5, we can see how this logic translates into behaviour: "commercial maize assemblage" and "informal grain retailing" reach zero around month 80. This means that all the maize that smallholders have not contracted to FRA and that was thus available for private buyers has been sold. As a result, the "non FRA smallholder sales switch" (reflecting the fact that farmers will reserve the rest of their maize for the more profitable FRA purchases) turns to zero. The flows of informal grain retailing and commercial maize assemblage therefore also drop to zero at that time. This means that the inflow of maize to the informal value chain stops and consumers respond by gradually lowering their monthly consumption, which makes ADESM gradually approach 0,84 as a response.

The problem with FRA's purchase and sales policies is not just that they often dry up the informal market, but also that they purchase much more than they can sell or want to store as security stocks. This leads to long residence times of the maize in their storages and ensuing high losses. Hence, at the end of the marketing year, they are faced with a bad choice: either let their excess maize rot away with exponentially rising loss ratios (cf. figure 6), or export it under unfavourable terms of trade.[2]

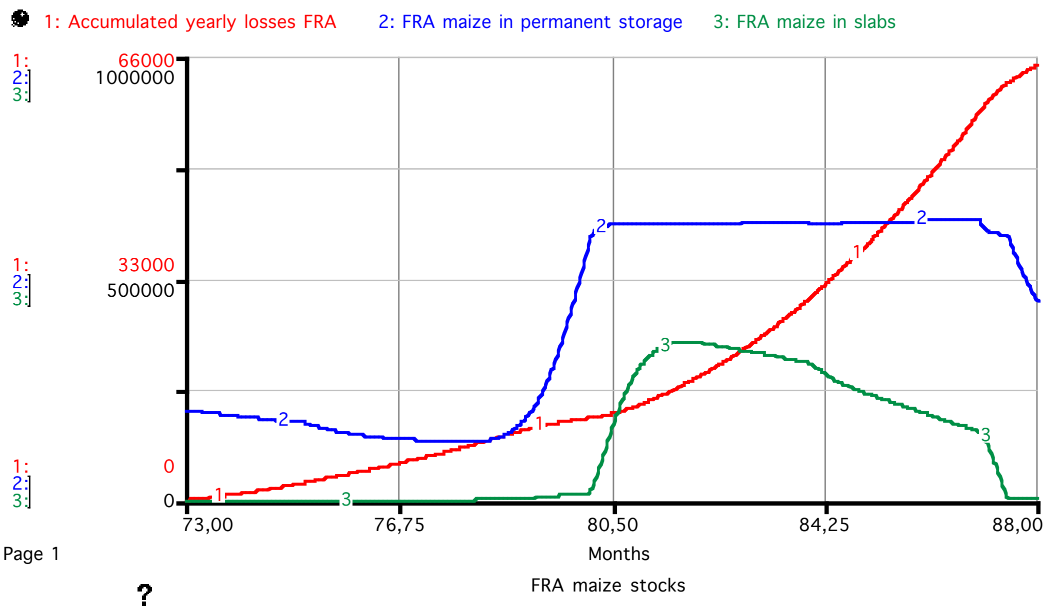

Figure 6: FRA storage losses

An exception to the constantly recurring mismatch between demand and supply described so far is the time between summer 2013 and summer 2015 (months 113-140), where the ADESM in figure 5 nearly constantly displays a value of 1, indicating the full satisfaction of maize demand. This is due to the fact that in 2013 and 2014, harvests were very good and FRA purchases sufficiently low, so that the available purchase volume for private traders was high enough to service the demand from the informal value chain throughout the whole year.

As you can see, the key to understanding the model behaviour really is the distribution of the smallholder maize sales: they determine if the maize goes into the formal or informal value chain, or is locked up at FRA's storage facilities and lost to pests. Once the maize has entered one of the value chains from the smallholder stocks, or is sold by FRA, it is processed and consumed according to the rules explained in chapter 3.2. However, since the relative distribution of smallholder maize sales between the value chains is not only

[2] These are due to the fact that FRA usually purchases maize at an above-market price that they cannot demand when selling maize abroad. They therefore often sell at a loss and it is just a matter of choosing the lesser bad for them in that situation.

determined by supply, but also the demand for smallholder maize in the form of the *DAR informal grain retailing* and the miller's demand driving the *commercial assemblage* flow.

Summing up, the following can be used as a rule of thumb for understanding the dynamics behind the fluctuations in our key parameter ADESM: it usually rises in May as the new harvest comes in, staying at a plateau value of one that indicates the full servicing of demand in both value chains. The grain supply then dries up either because the harvest was simply too small to satisfy total demand, or because FRA has locked up large amounts of maize in the formal value chain. ADESM then falls to a value around 0,84 indicating that people who would prefer to consume grain have to reduce their daily consumption and eventually resort to buying expensive maize meal. The time when this shift occurs depends on how much smallholder maize was channelled into the informal value chain. This in turn depends on the availability of maize in the formal and informal value chain in the preceding marketing year: if the supply gap in the informal value chain was greater than in the formal chain, the initial demand to refill stocks at the beginning of the marketing year is higher and the informal value chain therefore attracts relatively more maize.

If the total harvest in the current marketing year was smaller than total yearly demand, the supplies in the formal value chain eventually also dry up, leaving the ADESM to fall to zero. If it was a surplus year, ADESM stays at 0,84. As the next main harvest comes in in May, the cycle begins again. Only when the difference between smallholder surplus harvest and FRA purchases is big enough to allow private traders and grain retailers to satisfy demand for grain all year round, the ADESM stays at 1 throughout the whole year.

The sales by commercial farmers later in the year and the incoming green harvest in March and April do bring some relief in the lean season, but they generally are rather insignificant due to their small size in comparison to total yearly harvest and demand. Furthermore, as commercial farmers only sell to the formal value chain, their production does not help to reduce the gap in demand in the informal value chain, and thus will not change the value of the ADESM if it is at 0,84.

One more important determinant of the ADESM's behaviour is the existence of carryover maize stocks from last year. If the current year shows a structural maize deficit, the consumption of stocks that have been accumulated in a better preceding year can stabilize the ADESM.

4.2 Production Shock Scenarios

It was shown that the most relevant adverse impacts on the maize production would come from sudden changes (shocks) in the following parameters:

- Cultivated land
- Exposure to water
- Fertilizer Use

The most likely and relevant scenarios significantly altering these variables were found to be the following:

Exchange rate shocks

Such shocks reduce the purchasing power of the Kwacha in relation to the US Dollar, the currency in which fertilizer is internationally traded – which again increases the average price for fertilizer for Zambian farmers, as most fertilizer is imported. I assume a dynamic response of the economy; insofar steady high prices for imported fertilizer will make domestic production more attractive and thus reduce import rates.

Floods

Large floods cause significant losses in the cultivated land area.

Fertilizer subsidy shocks

Cuts in the fertilizer subsidy program for smallholder farmers reduce the amount of fertilizer that farmers can purchase and use.

Droughts

Droughts lead to a loss of cultivated area and lower yields due to a lack of rain and strong heat. A scale with 5 different drought strengths was used for different scenarios.

4.3 Simulation Results for the Different Scenarios

Following the methodology laid out in chapter 2, I will measure the resilience of the value chain in terms of the integral between the curves for the ADESM in the base run and the ADESM in the respective shock scenario runs. The maximal impact of a shock would thus be that the ADESM goes to zero for all the six years, or 72 months, simulated into the future. This would lead to an integral of 60 between the base run's ADESM and the shocked run's ADESM. The minimum difference is of course 0 when there are no adverse effects on the ADESM in the scenario run. Using this range as a yardstick, we can thus analyse the resilience of the value chain towards the different production shock scenarios in chapter 5. The simulation results are summarized in figure 8 below.

Scenario	Description of shock	ADESM integral final value
1	Permanent Increase in Kwacha Value Towards US Dollar by 35%	4,86
2	Permanent Increase Kwacha Value Towards US Dollar by 50%	8,49
3	Flood Loss of Cultivated Area by 10% in 2015	0,18
4	Flood Loss of Cultivated Area by 20% in 2015	0,45
5	Flood Loss of Cultivated Area by 30% in 2015	1,44
6	Flood Loss of Cultivated Area by 20% in two consecutive years (2015-16)	1,95
7	Extreme 3-year Drought (2015-17)	20,08
8	Extreme 2-year Drought (2015-16)	12,44
9	Extreme 1-year Drought (2015)	6,17
10	Severe 2-year Drought (2015-16)	10,33
11	Severe 1-year Drought (2015)	5,02
12	Moderate 2-year Drought (2015-16)	6,71

13	Moderate 1-year Drought (2015)	2,75
14	Extreme followed by Severe Drought (2015-16)	11,41
15	Steady Fertilizer Subsidies of 1500 Kwacha/Person/Year	0
16	Fertilizer Subsidies Permanently Cut in Half to 750 Kwacha per Person and Year	4,64
17	Fertilizer Subsidies Permanently Abandoned	13,88
18	Flood Loss of Cultivated Area by 20% and Zero Subsidies in 2015, followed by Subsidies Cut-in-Half to 750 Kwacha/Person/Year in 2016	3,96
19	Flood Loss of Cultivated Area by 20% in 2015 and 2017, as well as Permanently Abandoned Fertilizer Subsidies	18,48
20	Severe Droughts in 2015 and 2017 and Extreme Drought in 2016, as well as Reduced Fertilizer Subsidies in 2015 and 2018 (750 Kwacha/Person/Year) and No Fertilizer Subsidies in 2016-17	19,77
21	Severe Droughts in 2015 and 2017 and Extreme Drought in 2016, as well as Permanently Abandoned Fertilizer Subsidies	26,31
22	Extreme Droughts in 3 consecutive years (2015-17), as well as Permanently Abandoned Fertilizer Subsidies	27,41

Figure 7: Overview of production shock scenarios

5. Scenario and Resilience Analysis

Using the final value of the integral between the scenario and base run ADESM as a metric, we can evaluate the relative resilience of the value chain towards the different production shock scenarios. In order to keep the analysis as concise and informative as possible, I will group the scenarios according to the nature of the shock scenario and evaluate the resilience of the value chain to the different types of shock scenarios.

5.1 Exchange Rate Shock Scenarios (No. 1-2)

While currency shocks do have a significant impact on the ADESM, their accumulated effect is less pronounced in the medium to long term compared to the fertilizer subsidy and drought scenarios. In terms of our methodological framework, the initial vulnerability is not very high, but the permanence of the change undermines the adaptive capacity, so that in the third year, the maize buffer stocks (i.e. stocks maize stocks that are carried over from one year to the next to act as a security buffer in case of a shock) are depleted and the structural maize (production to demand) deficit that is growing bigger over the years, cannot be compensated any more. The ADESM therefore then breaks down to zero in 2017 (months 156 – 167) and the integral surges up.

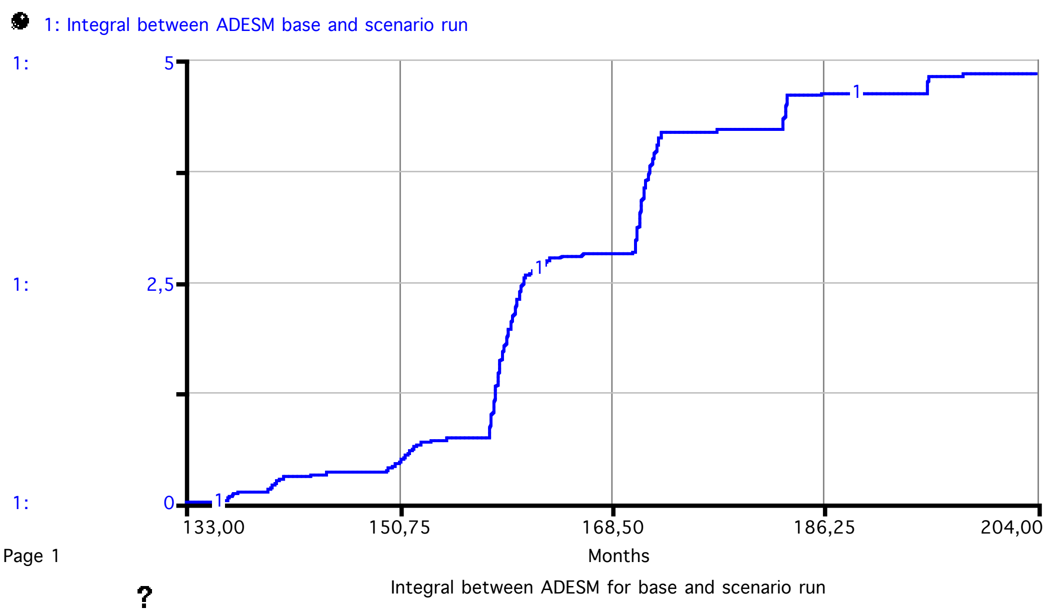

Figure 8: ADESM integral for scenario 1

However, due to the dynamic market response I assume, the producers compensate for the more expensive fertilizer imports by raising domestic production. This leads to decreasing marginal yearly impacts of the changed exchange rate value on the ADESM, as can be see by the decreasing growth of the integral. The adaptive capacity thus becomes stronger again over time.

5.2 Flood Loss Scenarios (No. 3-6)

The maize value chain in Zambia is quite resilient towards flood losses of cultivated area, as the relatively small maximal value of 1,88 for the impact of the flood scenarios shows. As can be seen by comparing scenarios 4 (one-year flood) and 6 (two-year flood), the adverse effects on the food supply rise exponentially when floods occur in two consecutive years: one year with 20% area loss has an effect of only 0,45, while the same event occurring in two consecutive years has an effect of 1,95. The impact is thus more than four times as high when the same flood loss shock is repeated in a consecutive year.

To investigate the reasons for this increasing impact, it we need to look at the change of maize supply over the flood years (2015-16). Maize can be supplied to consumers either from fresh production of the current year or from carryover stocks that were accumulated over the last years. Comparing the graphs for SC 6 and the base run in figure 9, we can see that the difference between yearly maize production in both actually becomes smaller in the second shock year of 2016. Changes in the production for the current year can therefore not explain the increasing impact.

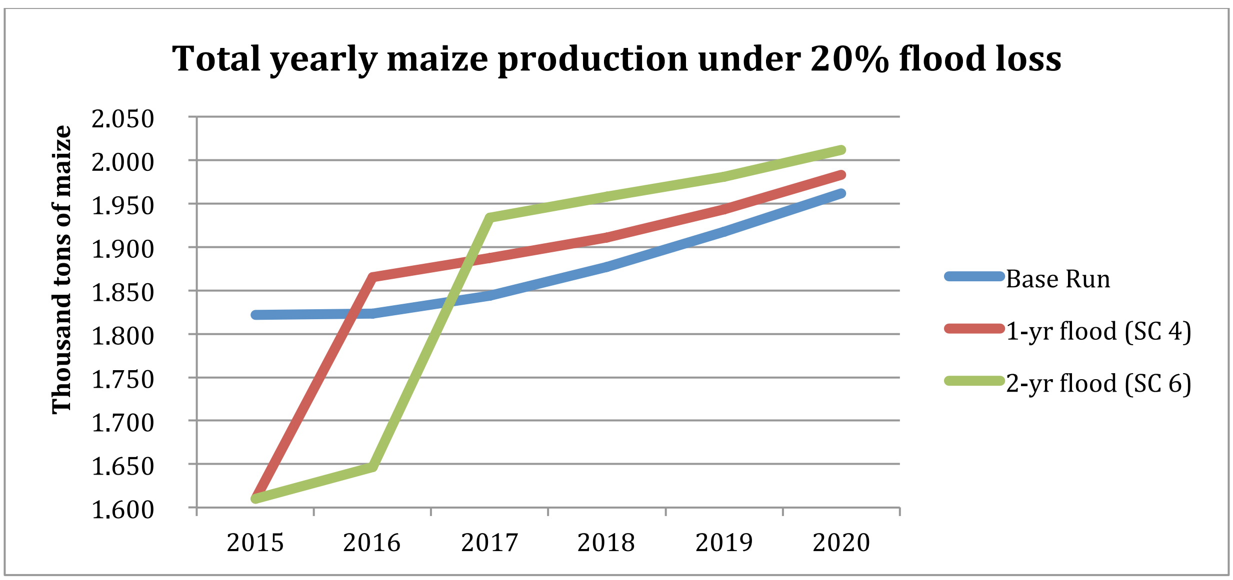

Figure 9: Total yearly maize production in scenario 4

The answer can be found in the difference of the total maize that is stored throughout the value chain: for this parameter, the difference between scenario 6 and the base run becomes much bigger in 2016, as buffer stocks had to be used up in order to maintain a sufficient supply in 2015 (see figure 9).

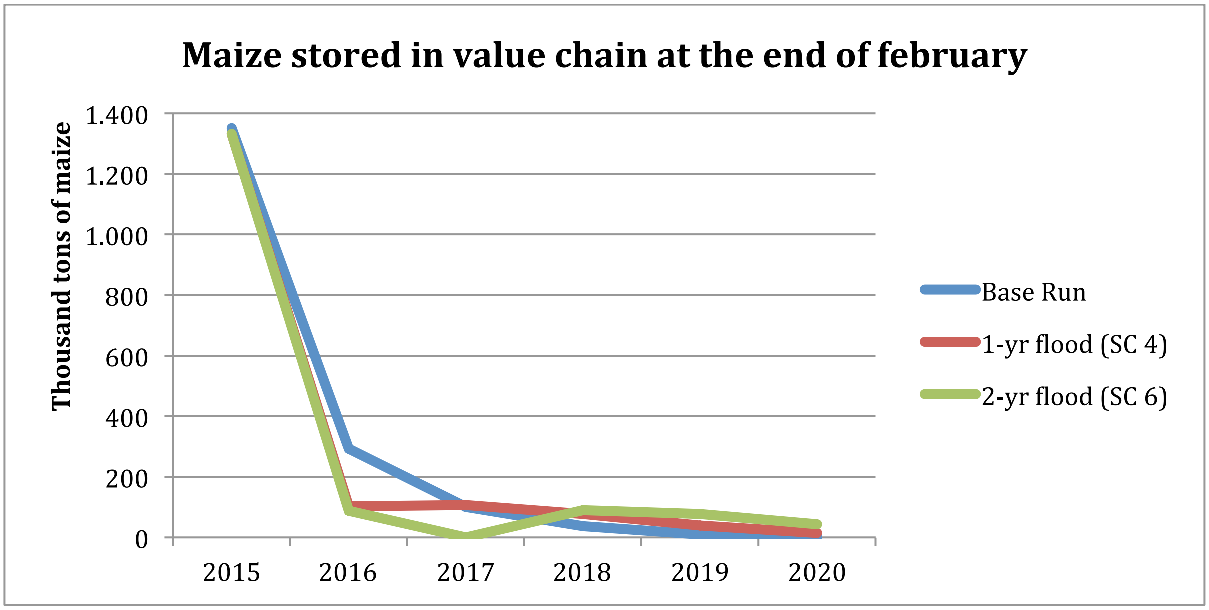

Figure 10: Total maize stored in value chain at the end of February in scenario 4

Since 2016 is a year with just enough production to prevent the ADESM from dropping to zero, stored maize stocks are consumed and reach virtually zero at the beginning of the 2017 marketing season. 2017, however, is a year with an even worse supply-to-demand ratio where buffer stocks would be needed even more. As these are now depleted, the low production can – other than in the base run and scenario 4, which feature enough buffer stocks, not be offset and the ADESM drops to zero, as can be seen in figure 11a.

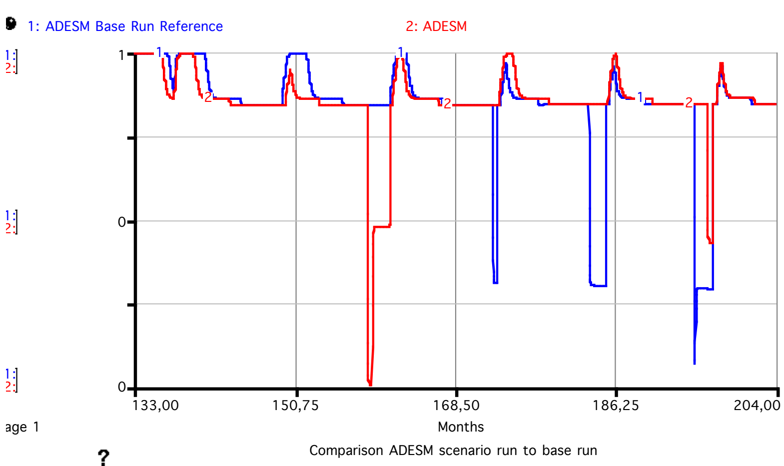

Figure 11a: ADESM comparison scenario 4

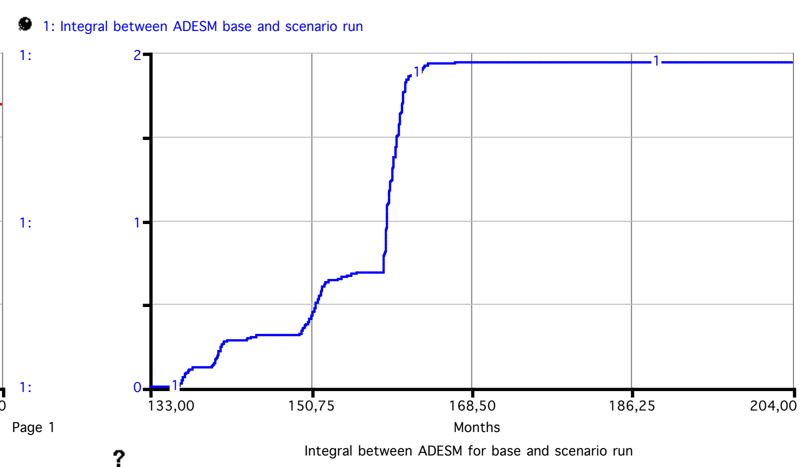

Figure 11b: ADESM Integral scenario 4

This drop of course leads to a strong increase in the integral between the scenario and base run ADESM (cf. figure 11b), therefore explaining the big difference between the two- and one-year flood scenarios.

These observations lead to an interesting conclusion: the initial vulnerability of the value chain to the flood-induced area losses is not that high, but there is a certain threshold of time with consecutive shocks, after which the system becomes very vulnerable to any further perturbation in the production due to the depletion of buffer stocks. We can thus attribute the resilience properties towards production shocks to two main factors: the change in yearly production itself, and the ability to buffer the effects of production shocks through carryover maize stocks from the preceding years.

The behaviour observed and described in the last paragraphs can be generalized across all the scenarios simulated: while differences between the base run and scenario ADESM normally are greatest in the years of the actual shock events, there usually is a lasting adverse effect buffer maize stocks. Looking at these stocks and the current production is the key to understanding the development of our resilience indicators.

The reader should note that in some scenarios, production lags behind in the years following the shock by a small margin, e.g. the drought scenarios; while in other scenarios yearly production actually overtakes the base run reference production due to a compensation response. The latter is the case for the flood loss scenarios. However, these responses are caused by dynamics in the production sector, are thus external and I therefore will not expand on this topic.

While there is not much that actors in the value chain can do to change the production output of maize, the finding about the buffer stocks is interesting in terms of my research question of how resilience properties can be enhanced. If it was possible to accumulate higher buffer stocks in the value chain, the impact of shock events could be mitigated and the resilience properties thereby ameliorated. This will be discussed in more detail in section 6.2.

5.3 Drought Scenarios (No. 7 – 14)

Drought scenarios have the highest impact of all the single-shock scenarios. In the case of three consecutive extreme droughts in scenario 7, the final integral value of 20,08 shows a substantial impact, which amounts to more than a third of the integral value that a complete loss of supply would cause. We can thus conclude that the value chain is very vulnerable to drought scenarios, mainly because the adverse effects of droughts on maize production are very substantial compared to other scenarios.

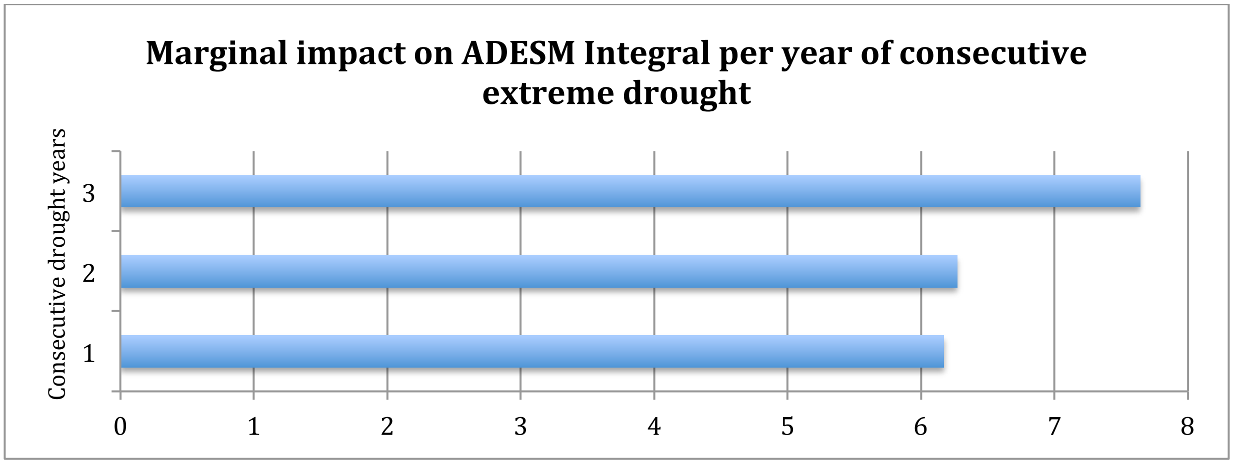

Figure 12: Marginal impact of consecutive extreme drought years on ADESM integral

Just like the flood scenarios, drought scenarios show an increasing marginal yearly impact on our resilience indicator. This is due to the same reasons as discussed for the flood scenarios, namely the progressively depleted buffer stocks. However, since the overall loss in yearly production is much higher in these scenarios, the effect of change in current production is so great that the effect of the buffer stock development is relatively less important. This can be seen by the small relative growth in marginal impact compared to the flood loss scenarios, displayed in figure 12.

5.4 Fertilizer Subsidy Scenarios (No. 15 -17)

The fertilizer subsidy shock scenarios are different from the other classes of shocks, as the system faces a permanent change without a built-in compensation response like in the exchange rate shock scenarios. Subsidies are cut in half (scenario 16), or abandoned completely (scenario 17) in 2015 and then stay that way all through to 2020. This leads to production constantly being around 6,5% lower every year compared to the base run in scenario 16 and around 19,5% lower in scenario 17 throughout all six years. Looking at the graphs for scenario 16, we can see how this translates into changing our resilience indicators.

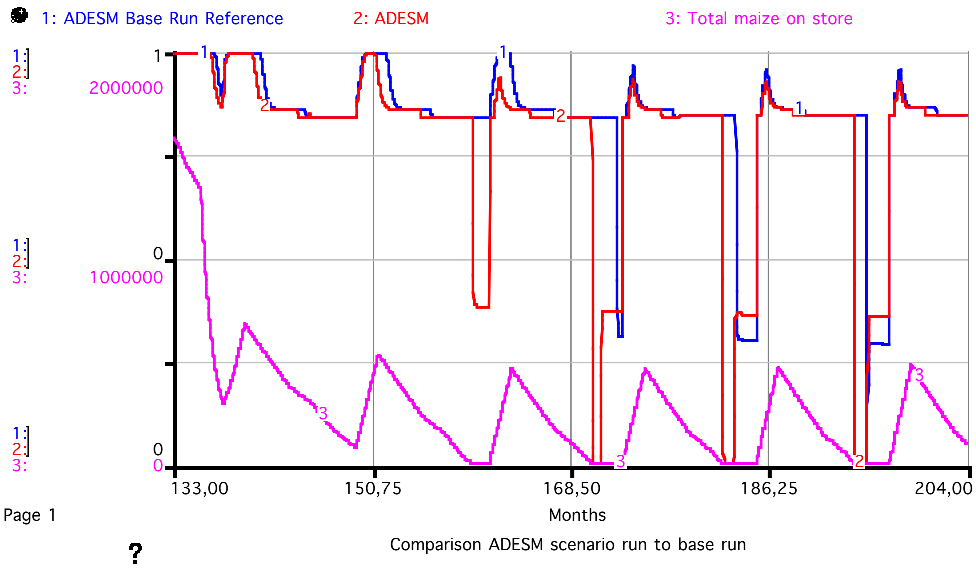

Figure 13: Comparison of ADESM and maize stocks scenario 16

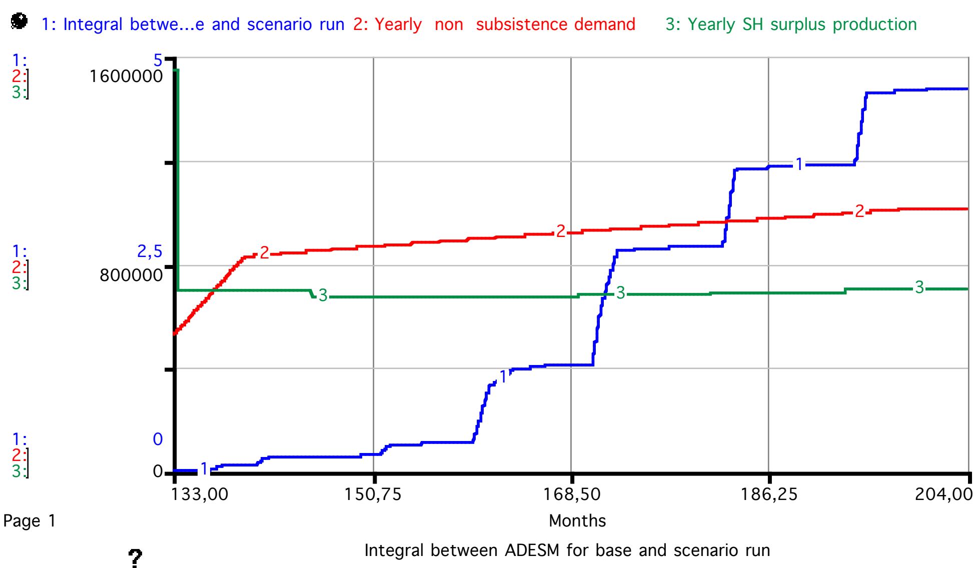

Figure 14: Development of ADESM integral against yearly demand/production scenario 16

The logic behind the behaviour of the resilience indicators is similar to the one explained in the preceding sections: there is only a relatively small excess original demand[3] (i.e. demand exceeding production) in 2015, so that the production deficit can be buffered by the consumption of carryover stocks. The size of the carryover stocks is represented by the local minima of the purple line in figure 13. In 2016, however, the difference between production and original demand rises and the buffer stocks are now lower than the year before. The growing gap in 2016 cannot be redeemed by consuming the already reduced buffer stocks and the ADESM drops to zero later in the 2016-17 marketing year. The permanently low production and the rising population lead to an ever-growing gap in demand vs. production that does not allow carryover stocks to be built up. This leads to the breakdowns in ADESM becoming progressively bigger in every consecutive year's lean season. The only reason why the growth of the integral slows down in 2019-20 (months 181-204) is that the base run also performs worse over time.

While the initial vulnerability is quite low, as indicated by the shallow initial growth of the integral, due to the permanence of the effect, the adaptive capacity of the system is undermined as buffer stocks are depleted. The shock effects therefore accumulate to a significant level in the long run. If the shocks were only to occur in one or two consecutive years, the impact on the ADESM would be comparatively small, probably comparable to what we have seen for the flood loss scenarios. I therefore conclude that resilience of the value chain towards shocks in the fertilizer subsidies is relatively high compared to other shock types when they feature the same number of impact years.

Before moving on to discuss the combined scenarios, I would like to draw the reader's attention to a phenomenon that is important in understanding the resilience analysis. There is effectively a "threshold" behaviour for the ADESM in my model: since there are only effectively two compensation mechanisms in terms of demand adjustment when maize becomes scarce (eating less per day and changing to other carbohydrate sources), the ADESM either stays at 0,84 where both mechanisms are at play and the consumption is sufficiently reduced to not exceed supply – or it collapses to zero very quickly as all maize stores in the value chain are depleted. Whenever this sometimes-fine threshold is crossed

[3] „Original demand" refers to the demand before it is adjusted for dynamic consumer responses to scarcity

and the ADESM thus falls to zero in the scenario run, but just manages to stay at around 0,84 in the base run, the integral surges up.

5.5 Combined Scenarios (No. 18-22)

The combined scenarios have – except for scenario 18 – a very strong impact on the ADESM. The impact of the combined scenarios reflects what we have found out about the resilience of the value chain to the different single-shock scenarios: the lower the resilience of the value chain is to the single shocks that make up the combined scenario, the greater is the impact of the combined scenario as well. The underlying dynamics of the translation of production shocks to changes in the ADESM are essentially the same as described in the preceding sections and I will thus not go into detail about them again.

An interesting observation is that the combined scenarios have a lower impact on the ADESM than the sum of the two single-shock scenarios. For example, the 3-year extreme drought leads to a final value of the integral of 20,08 and the abandonment of fertilizer subsidies to an integral of 13,88. Yet, the impact of the combined shock scenario 22, featuring both of these developments, does not amount to an integral value of 33,96, but instead only 27,41. The reason for this is that the production sector shows a decreasing marginal impact on yearly maize production when shocks are added up.

5.6 Conclusions Resilience and Scenario Analysis

To close this part of my analysis, I want to sum up the most central findings from this chapter:

- The value chain is **quite resilient** towards **flood events** causing loss of cultivated area, as well as towards **exchange rate shocks**.
- The value chain is **moderately resilient** towards **fertilizer subsidy shocks**. The moderately strong effect of these scenarios is mostly attributable to the permanence of the change. The effect can be expected to be rather small when assuming that the shock only lasts one or two seasons, as the initial vulnerability of the value chain towards fertilizer subsidy shocks was shown to be low.
- The value chain is **vulnerable** towards a **prolonged drought**. While a drought lasting only one year still has only limited impact and its effects on the ADESM can

be mitigated through the consumption of carryover stocks, already a second consecutive medium to extreme drought year depletes the buffer stocks and unfolds increasingly strong impacts on the maize supply.

- Even though there is a decreasing impact on the ADESM when combining two shocks, the value chain is generally very vulnerable towards a combination of shocks hitting it simultaneously or consecutively.
- In general, the resilience of the value chain towards a one-time shock (only occurring in one production season) is quite good and it exhibits a low initial vulnerability. However, as soon as it is faced with consecutive shocks, the adaptive capacity quickly wears off as buffer stocks are soon depleted after one or maximum two years, and the impacts on the ADESM become very significant.
- There are two main determinants for the effect that a shock has on the ADESM in the value chain: the change in the current year's production, and the availability of carryover stocks that can act as a buffer. The policy analysis in the next chapter will therefore focus on how buffer stocks can be used to enhance the resilience properties of the value chain.

5.7 Impacts of Model Structure on Resilience Properties

Trying to keep the analysis of the different resilience responses of the model as concise as possible, I focused on the most important impact factors that actually change in between the scenarios and therefore explain the differences observed. These are, as we learned in the preceding sections, the current year's maize production and buffer stocks. The model structure itself did not change across the scenarios, wherefore I did not explicitly mention its effects on the ADESM in the previous sections.

However, the feedback structure of the value chain model naturally has a significant influence on the results of the resilience analysis. Running different "structural scenarios" by turning switches and loops on and off revealed the following:

- The demand spill-over loop (C2) represents a very strong mechanism to cope with food insecurity. The fact that consumers change to other crops, as well as the fact that informal consumers buy around 20% less maize meal (due to higher prices) than grain when being forced to change does, significantly lowers overall demand.

This reduces pressure on the maize market and leads to longer coverage of demand with existing maize volumes. The importance of this mechanism can be seen by the fact that the ADESM integral for scenario 16 would rise by 232% if one deactivated this loop.

- Less important, but still significant is loop C1 that represents how consumers in the informal value chain reduce their demand in times of dwindling grain supply / rising prices. By reducing demand, this loops has similarly beneficial effects on the ADESM as loop C2. Even though the lowered consumption leads to an ADESM of around 0,84 instead of 1 (and thus a rising integral), the fact that consumers can eat maize at a reduced level for longer before the supply breaks down completely leads to a smaller overall integral – meaning that resilience is higher due to the effects of C1.
- Another important coping mechanism that lowers the ADESM integral for a given shock scenario is loop C3: FRA's decision to offload buffer stocks in years of maize deficit helps to stabilize the maize supply and thus food security. However, the strength of this loop's impact depends on the size of FRA's reserves: i.e. if the preceding year's maize production was so bad already that FRA offloaded most of its reserves, very little impact can be achieved through this mechanism.

6. Policy Analysis

After having evaluated the resilience properties of the value chain in chapter 5, in the following section I want to explore how the can endogenously be improved. With results showing that buffer maize stocks play a crucial role in determining the resilience of the value chain towards production shocks, I designed policy interventions that aim to promote the creation of those stocks.

6.1 Policies Under Base Run Assumptions

The policy I want to test is rather straightforward and relies on existing structures that are already well established. Namely, I want to see what happened if FRA would try to fulfil its original mandate: increasing food security for Zambians by buying and keeping strategic maize reserves as buffer stocks. The stocks would only be released in times of maize deficits. To test the effect of such storage policies under different circumstances, I simulated them in a low-impact scenario with permanent change (scenario 16), as well as a high-impact scenario featuring a shock of limited duration (scenario 8).

The results show that in an environment of consecutive structural maize deficit years, it does simply not make sense to accumulate maize stocks in one year and release it in another, since all one achieves with that policy is to improve the food security situation in one year by worsening it in another. This policy has no significant positive effect on the resilience metrics and is furthermore hardly economically feasible: it is hard to imagine that people would be okay with taking maize out of the market in a deficit year for the sake of storing for eventual future use in worse years.

6.2 Policies Under Changed Scenario Assumptions

Having thus established that policies relying on storing domestically produced maize are not promising in an environment of constant structural maize deficits, I want to explore the effects of storage policies in an environment with occasional bumper harvests – which, as we know from historical data, do regularly occur in Zambia (cf. appendix A.1).

To investigate the effects of the policy, I will use a new scenario (No. 23), which features base run production in 2015-16, then a high production year in 2017, followed by two shock years in 2018-19 and base run production in 2020 again.

The policy that I want to test is for FRA to accumulate large buffer stocks in years with bumper harvests and lock up the excess production (the amount of yearly production that exceeds yearly demand) in their storages with the intention to keep these stocks constant at that level, unless they need to release it in case of emergency. An emergency is defined as a time when the ADESM would fall below a value of 0,8 without policy intervention.

In the case of scenario 23, this policy will cause FRA to keep 515.000 tons of their purchases in the bumper harvest year of 2017 as a strategic reserve, and then release 390.000 tons in the first shock year of 2018 to keep the ADESM over 0,8. This leaves them with 125.000 tons to spend in the second year. The uneven distribution over the two drought years is due to the assumption that they cannot foresee the second drought coming and need to keep the ADESM from collapsing to less than 0,8 in the first year. This assumption seems credible, as it would hardly be justifiable for FRA to not release these emergency relief stocks in the first drought year, just by pointing at the vague possibility of second shock coming up next year. Running the simulation with and without the policy intervention, we get the following results for our resilience indicator:

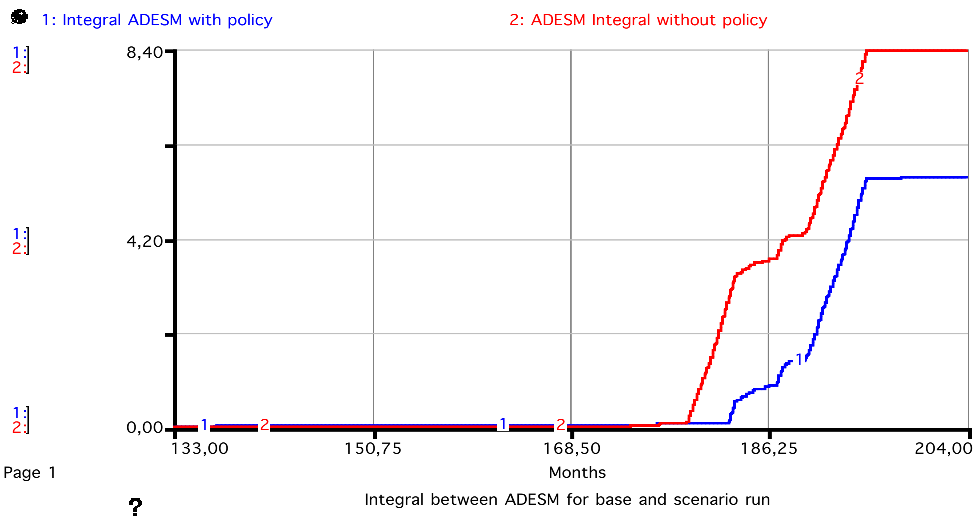

Figure 15: Integral between ADESM for base and scenario run in scenario 23

Looking at figure 15, we can see that the ADESM performs significantly better when the policy is in place. The "no policy" run of the scenario featured a final integral between the scenario ADESM and the base run ADESM of 8,39 – while the integral in the "with policy" run only amounted 5,56. This is a reduction by more than one third. Note that the total production over the years is exactly the same in both runs; the only change is the policy of FRA to store bigger amounts of maize in surplus years and not export the excess maize at the end of the respective surplus year. We can thus conclude that an intelligent storage policy by FRA that exploits the frequent occurrence of surplus harvest years can significantly enhance the resilience of the value chain to production shocks – without any exogenous help or inputs from outside Zambia.

6.3 Feasibility of the Proposed Policy

To conclude the policy analysis part, I want to address the feasibility of the proposed policy. While I have argued that it is neither desirable nor politically feasible to accumulate maize buffer stocks in years of structural maize deficit, the policy proposed and tested in section 6.2 appears to be useful and feasible, as I will show in this section. Possible frictions that might hinder the implementation of the proposed policy can arise from political opposition, storage capacity problems leading to high losses, and funding shortfalls for FRA. I will discuss these problems in turn below.

Looking at **political pressures** that always have a big influence on the decisions taken in politically controlled organizations like FRA, I can see no reason why an accumulation of excess maize in surplus years should trigger political resistance or public outrage.

Loss of maize in FRA storages is actually a very valid concern when trying to implement a policy that requires storing large amounts of maize for long times, potentially over years. While FRA does possess large shed capacities, maize stored in sheds is subject to excessive losses after just a few months of residence time: after one year, we can expect a loss ratio of more than 50% and after 1,5 years even more than 80% (cf. appendix C.3). However, Bou Schreiber (2015) expects FRA to keep on increasing their silo construction so that by the end of 2019, they will have silo capacities of nearly 250.000 tons. This means that a great portion of the maize can be stored in a way that produces almost no significant losses (less than 3% even after 1,5 years of storage time).[4] Furthermore, if FRA keeps up a steady flow of maize through their storage by mixing and selling maize from last year while stocking up fresh maize, they can limit the residence time and thus the loss ratio to reasonable amounts, even in the sheds. I therefore believe that the storage loss problem can be adequately addressed and will ultimately not hinder the implementation of the proposed policy.

The biggest threat for implementation is in my opinion the fact that FRA would need steady and significant funding over a long time in order to properly execute the storage policy proposed. **Funding for FRA** has been fluctuating quite a lot over the decades and was always subject to often-arbitrary discretionary political decisions (N. Mason, 2011). Furthermore, funding a storage programme will not immediately bring benefits that can be presented to the electorate and there are opportunity costs of allocating funds to the proposed policy, since that money then cannot be used for other, maybe more popular programmes like consumer price subsidies or other poverty reduction measures. I therefore see a real danger that policymakers might, especially in pre-election periods, re-allocate the funds from FRA's buffer stock programme to other measures that reap instant

[4] For details on the storage loss ratios, see appendix C.3

benefits for the population. However, in the end the funding decisions depend on the government's will to follow through with a policy and it therefore *can* work if there is sufficient political will to do it.

6.4 Change in FRA's Sales Policy

Another change in policy I strongly want to suggest is that FRA should start selling maize to grain retailers supplying the informal value chain. The current policy of just selling to big commercial millers actually "locks up" maize in the formal value chain, which is eventually often either exported under unfavourable terms or lost in inappropriate FRA storages, while customers in the informal value chain at the same time cannot satisfy their demand for cheap grain and have to reduce consumption. This obviously inefficient policy leads to the ADESM taking on a value of around 0,84 instead of 1 even in surplus years, as can be seen for the years 2010-12 (months 73 – 96) in figure 16.

This problem can easily be avoided by a simple policy change requiring FRA to open their sales to grain retailers as well. This policy would actually help them fulfil their original mandate – increasing food security for the Zambian population as a whole – much better and more efficient. To illustrate the effects of this policy, I simulated the ADESM for the months 73-96 with and without the proposed FRA sales policy. The results in figure 16 show that the performance of the ADESM would have been enhanced significantly.

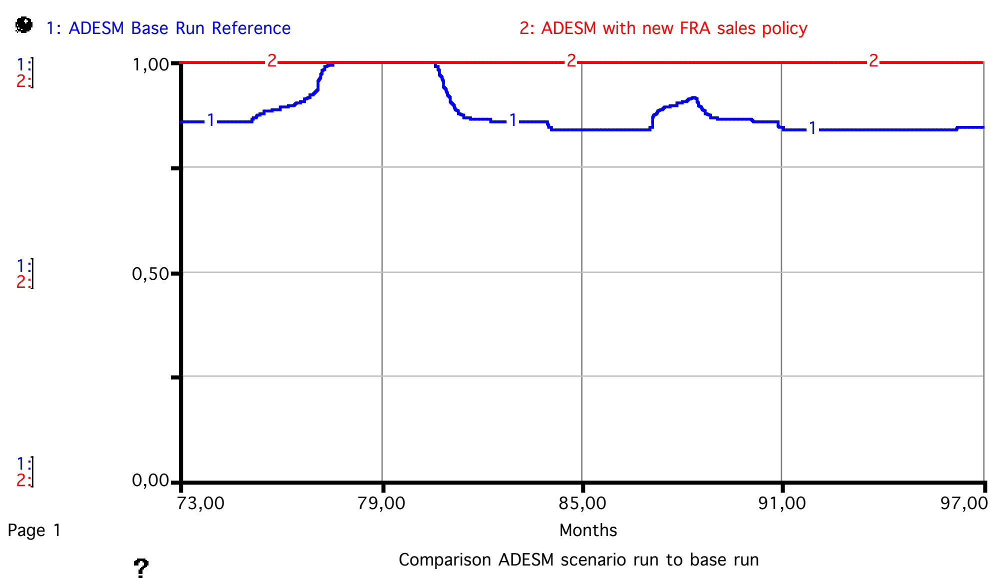

Figure 16: Comparison ADESM development of old and proposed FRA sales policy

Concerning feasibility of this policy change, I do not see any big obstacles to implementation. Since FRA has maize storages all over the country, FRA officials could just go there during a number of fixed sales days and administer the exchange of maize against money – much like they do when they buy maize grain from smallholders, just the other way around. Moreover, such a policy change can be expected to be popular in the electorate, as helps the majority of consumers to gain better access to their preferred form of maize.

7. Conclusion

7.1 Overview of Results

The general result was that the resilience of the value chain towards one-year shocks is quite good, as the ADESM exhibits a low initial vulnerability due to the existence of buffer stocks in the chain that can be consumed as a substitute for lacking fresh production. However, as soon as the value chain is faced with several consecutive shocks, resilience is low: the adaptive capacity quickly wears off as buffer stocks are soon depleted after 1-2 years, and the food supply breaks down. We furthermore found that there are two main determinants for the effect that a shock has on the ADESM in the value chain: the change in the current year's production, and the availability of carryover stocks that can act as a buffer.

Yet, as discussed in chapter 2, resilience can only be understood as resilience towards a specific shock, and we therefore needed to disaggregate the results into the different types of shocks. In doing so, we learned that the value chain is quite resilient towards exchange rate shocks due to the dynamic response of the production system assumed, as well as towards flood events causing a loss of cultivated area. In the case of shocks affecting the fertilizer subsidies, the value chain is rather vulnerable when these changes become permanent, but can be expected to show a relatively small vulnerability if the changes only last 1-2 years.

However, the value chain is very vulnerable towards a prolonged drought. While a one-year drought still has only limited impact and its effects on the ADESM and can be mitigated through the consumption of carryover stocks; already a second consecutive medium to extreme drought year depletes the buffer stocks and leads to increasingly strong impacts on the maize supply. Finally, in the case of two different types of shocks hitting the value chain simultaneously or consecutively, resilience has proven to be low. The adaptive capacities in the form of buffer stocks are insufficient to alleviate the effects on the ADESM and the food supply quickly falls to threateningly low levels – even though the marginal impact of a given shock on the maize production decreases as shocks accumulate in a combined scenario.

Concerning the relation between the model's structure and the resilience exhibited towards production shocks by the value chain, we found out that the two consumption adjustment loops have an especially strong impact on the resilience properties due to their direct influence on the computation of the ADESM via changes in demand. The reduction of demand in response to the changing availability of grain in the informal value chain, as well as the behaviour of informal consumers to change to other crops and roller meal when supply in the informal value chain dries up, both significantly improve the resilience in response to a given shock. These coping mechanisms reduce demand for a given supply and therefore improve the ratio that determines the ADESM.

Moreover, the non-FRA smallholder sales switch and the information feedback structure of the informal and formal value chain were shown to affect the distribution of maize between the two value chains. And since consumers respond differently to supply changes in the informal value chain due to the two consumption adjustment loops, this distribution in turn affects the ADESM. Furthermore, the FRA reserves switch structure and the feedback structure of the value chain determine which actors build up how much storage stocks throughout the value chain – which in turn influences the extent of buffer stocks available to mitigate the impact of a given shock on the ADESM.

Analysing policies that can improve the resilience properties, we learned that the key to endogenously improve performance was the creation and maintenance of buffer stocks. However, it became clear that building up carryover stocks in an environment of permanent structural maize deficits was neither desirable in terms of its effect on the resilience metrics, nor politically feasible. Yet, I showed that a smart storage policy, using FRA's infrastructure and exploiting the frequent occurrence of surplus production years, could significantly improve the resilience towards production shocks. Furthermore, the feasibility of such a policy seemed promising under a few conditions, which were that FRA keeps expanding its silo capacity as predicted by Bou Schreiber (2015), keeps a steady flow of maize through its storages and that the storage programme is backed up by sufficient political will. Lastly, I showed that the often inefficient distribution of maize in between the formal and informal value chain, which can lead to supply shortages even in bumper harvest years, could easily be remedied if FRA changed its sales policy in a way that also allowed sales of maize into the informal value chain.

7.2 Discussion of Methodological Framework

Apart from the main goal of yielding insights about the structure, dynamics and resilience properties of the maize value chain in Zambia, my work also served as a test for the usefulness of my framework for quantified measurement of resilience in an SD simulation model. I therefore shortly want to evaluate how the framework has performed.

Comparing using this framework to the "usual ways" of analysing the behaviour of SD models by graphically comparing the development of a host of variables, I feel that the firm focus on one metric helped to get a much clearer picture of the value chain's capacity to maintain a sufficient food supply in response to the different production shocks. Using the ADESM integral as a metric, we received a fine relative scale that allowed comparing the strengths of the impact between the different scenarios more precisely. Moreover, the distinction between initial vulnerability and adaptive capacity helped to add further clarity to the discussion of the shock responses.

The major drawback of using this method is probably the lack of an absolute scale – the values of the integral only make sense in relation to each other and cannot be compared to some form of general metric. The next step in developing a System Dynamics resilience measurement framework would be to define an upper bound of a shock's effect on the integral of the FOM and compute the respective actual shock's magnitude as a ratio of that. This would allow the comparison of different system's resilience towards a given shock.

7.3 Limitations and Areas for Further Work

Maize alone, as overwhelmingly important as it is for the food supply in Zambia, does not determine the food security situation on its own. Even though agricultural productivity is probably correlated between different crops, as their yields are determined by similar parameters, one can imagine a year with a bad maize harvest and a good harvest for other crops that may act as a substitute. In that case, a low ADESM for maize might not be so much of a problem, as consumers could relatively easy change to other food sources. To reflect the situation in Zambia more holistically, it would therefore be necessary to model the value chains for other crops as well – something I unfortunately did not (yet) have the time and resources to do. However, the literature I consulted suggested that the distribution channels for other important crops in Zambia are structured in a similar way to the maize value chain, so that future research could build on the basic model structure that I carved out for maize, and adapt it to represent the value chains for other crops.

Another interesting avenue to expand this work would be to investigate the access dimension in the model in greater detail. However, this would most probably require to explicitly model prices. Since there is hardly enough comprehensive information about prices at the different stages of the value chain, as well as their seasonal fluctuations that drive the demand dynamics, further work in that direction would require field research.

Having only investigated the effects of production shocks, it would be interesting to also look at the resilience of the value chain towards energy and transportation shocks. The latter would require including spatial dimensions into the model, as the impact of shocks affecting the transportation capacity of a given physical flow in the model would depend on the distances covered in that link. A way to go about this could be to compute averages for the distances maize typically travels from stage A to stage B in the value chain. This average could then be used to model the degree of impact that the shocks disturbing the transportation capacity of the flow would unfold. The means of transportation that are typically used in that flow would probably also have to be accounted for in such an effect variable. However, I did not find appropriate information about this in the secondary data or literature, so that researchers looking at this phenomenon would probably need to go to Zambia for first-hand data collection.

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APPENDIX

A.1: Maize Production Data

	Maize production in metric tons				
	Total maize production	Commercial farmers	Smallholder total production	Smallholder surplus	Smallholder subsistence
2004	1213599	48579	1165021	343878	821143
2005	866187	65613	800574	178803	621771
2006	1424439	84960	1339479	564348	775131
2007	1366158	97099	1269059	647863	621196
2008	1211566	85578	1125988	522033	603955
2009	1887010	229893	1657117	613356	1043761
2010	2795483	331960	2463523	1062010	1401513
2011	3020380	233484	2786896	1663043	1123853
2012	2852687	220521	2632166	1362812	1269354
2013	2532800	195793	2337008	1215244	1121764
2014	3350671	259016	3091655	1550346	1541309
2015	1821490	66219	1755271	761513	993758
2016	1823090	64551	1758539	742338	1016201
2017	1843830	64258	1779572	738971	1040601
2018	1877020	64792	1812228	745113	1067115
2019	1917240	65768	1851472	756334	1095138
2020	1961300	66966	1894334	770112	1124222

Sources for maize production data:

- All data projections from 2015-2020 are based on simulations from Gerber (2015)
- Total maize production:
    - 2004 – 2013: CSO Zambia (2015: data sheet "maize production timeline")
    - 2014: Chapoto et al. (2015)
- Total smallholder production:
    - 2004 – 2011: N. M. Mason & Myers (2011)
    - 2012 – 2014: Triangulated from total maize production assuming a steady relation between commercial and smallholder production

- Smallholder surplus:
  - 2004 – 2011: N. M. Mason & Myers (2011)
  - 2012 – 2014: Triangulated from other sources as: Smallholder surplus = total maize traded (Kuteya, Sitko, & Inn, 2014) – commercial production
- Commercial farmers:
  - 2004 - 2011: Triangulated from other sources as:
    Commercial production = total production – total smallholder production
  - 2012 – 2014:
    Triangulated from total maize production assuming a steady relation between commercial and smallholder production
- Smallholder subsistence:
  - 2004 – 2012: Triangulated from other sources as:
    SH subsistence = total smallholder production – smallholder surplus
  - 2013: Triangulated from smallholder production assuming ratio of subsistence consumption staying steady for two years.
  - 2014: Triangulated from smallholder production with information about subsistence ratio from (Chapoto, Chisanga, Kuteya, & Kabwe, 2015)

A.2: FRA Data

	F.R.A. Parameter in metric tons				
	Yearly purchase	Desired reserves	Shed capacity	Silo capacity	Imports
2004	105279	0	539200	55720	9400
2005	78667	0	567020	55720	38950
2006	389510	0	566430	55270	119700
2007	396450	0	566410	55060	1458
2008	73876	0	566460	54960	1015
2009	198630	0	566480	54930	42027
2010	878570	131786	566480	54930	5704
2011	1579891	236984	590950	57370	2911
2012	1044998	156750	652990	63540	0
2013	422391	63359	737320	71920	0
2014	1031303	154695	833910	82460	0
2015	380757	76151	932780	99130	0
2016	371169	74234	1026640	125610	0
2017	369485	73897	1111110	164140	0
2018	372556	74511	1179570	212660	0
2019	378167	75633	1204760	244410	0
2020	385056	77011	1211838	248011	0

Sources for FRA Data:

- Yearly purchase:
  - 2004 – 2010: N. M. Mason & Myers (2011)
  - 2011 – 2013: Kuteya et al. (2014)
  - 2014: Chapoto et al. (2015)
  - 2015 – 2020: Assuming FRA wants to purchase 50% of smallholder surplus production
- Desired reserves:
  Derived from the yearly purchase under the assumption that FRA wants to keep 20% of their yearly purchase as reserves.
- Silo capacity:
  Bou Schreiber (2015)
- Shed capacity:

Bou Schreiber (2015)

- Imports:
  - 2004 – 2014: FAO (2015a: Timeline under "Trade -> Crops & livestock -> Zambia")
  - 2015 – 2020: Assuming no imports take place

A.3: Storage Loss Data

	Accumulated storage Loss in per cent		
Residence time (months)	Silo Loss	Shed Loss	Slab Loss
1	0,00%	0,72%	5,72%
2	0,28%	1,61%	6,61%
3	0,81%	1,83%	6,83%
4	0,82%	4,47%	9,47%
5	0,83%	6,50%	11,50%
6	1,36%	10,12%	15,12%
7	1,66%	14,97%	19,97%
8	1,86%	20,61%	25,61%
9	2,04%	26,86%	31,86%
10	2,20%	34,09%	39,09%
11	2,34%	42,22%	47,22%
12	2,46%	51,23%	56,23%
13	2,56%	61,14%	66,14%
14	2,64%	71,93%	76,93%
15	2,70%	83,62%	88,62%
16	2,74%	83,62%	88,62%
17	2,76%	83,62%	88,62%
18	2,76%	83,62%	88,62%

Sources for storage loss data:

- All data from Bou Schreiber (2015)

A.4 Roller Meal to Consumer Made Hammer Meal Price Relation Data

	Price August (ZMK/kg)				
	Lusaka	Kitwe	Mansa	Kasama	**Mean**
Breakfast meal (25 kg bag)	1391,0	1421,0	1505,0	1373,0	**1422,50**
Roller meal (25 kg bag)	915,0	975,0	1093,0	1000,0	**995,75**
Ratio breakfast of commercial meal	0,90	0,87	0,66	0,93	**0,84**
Composite commercial meal	1342,0	1362,2	1363,8	1348,4	**1354,09**
Consumer made meal (hammer mill)	1063	912	910	941,00	**956,50**
Relation roller meal to grain price					**1,42**

	Price February (ZMK/kg)				
	Lusaka	Kitwe	Mansa	Kasama	**Mean**
Breakfast meal (25 kg bag)	1536,0	1562,0	1750,0	1706,0	**1638,50**
Roller meal (25 kg bag)	1188,0	1261,0	1408,0	1408,0	**1316,25**
Ratio breakfast of commercial meal	0,92	0,88	0,62	0,96	**0,84**
Composite commercial meal	1506,9	1525,1	1620,1	1694,3	**1586,62**
Consumer made meal (hammer mill)	1185	1138	1336	1455	**1278,50**
Relation roller meal to grain price					**1,24**

Source: Nicole Mason & Jayne (2009: tables 10 & 11)

Price relation values plotted over the year assuming steady change from lean to plenty season yields this final relation:

Yearly Counter	Price relation
1	1,27
2	1,24
8	1,42
12	1,30

A.5 Urban Consumption of Meal Types Data

	Commercial meal	Hammer mill meal
Lusaka	0,899	0,101
Kitwe	0,855	0,145
Mansa	0,606	0,394
Kasama	0,317	0,683
Average	**0,669**	**0,331**

Source: Nicole Mason & Jayne (2009: tables 10-11)

Categories “consumer made maize meal via taking grain to grinding mill” and “maize meal made at grinding mill and sold by a vendor/retailer” were aggregated to “hammer mill meal” and the categories “samp” and “green maize” were excluded from the calculation to obtain the final ratio visible in the table above.

A.6 Production Inputs for Scenario 23

Year	Smallholder surplus	Commercial farmers	Subsistence Production	Data taken from scenario
2015	761513,4	66218,6	993758,0	Base Run
2016	761513,4	66218,6	993758,0	Base Run
2017	1370691,08	248154,7	1291558,5	High Production
2018	395346,1	34377,9	704086,0	Shock (SC8)
2019	363404,6	31600,4	691625,0	Shock (SC 8)
2020	754799,3	65634,7	1111506,0	Base Run