# Modeling regional market integration: Application to policy simulation in Eastern and Southern African maize markets

by

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## DECLARATION

I, P Davids, declare that the dissertation, which I hereby submit for the degree PhD Agricultural Economics at the University of Pretoria, is my own work and has not been submitted for a degree at this or any other tertiary institution.

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| | December 2017 |
| Signature | Date |

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Tracy

Modeling regional market integration: Application to policy simulation in Eastern and Southern African maize markets

by

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# ABSTRACT

The need for a vibrant and sustainable agricultural sector in Africa was recognised by the African Union in its Maputo declaration on agriculture and food security in 2003. Member states committed to allocating at least 10% of national budgetary expenditure towards implementation of the Comprehensive African Agricultural Development Program (CAADP). Despite these efforts, Africa remains the largest recipient of food aid in the world and over the coming decade, population growth in Sub-Saharan Africa is projected to exceed any other region globally. Consequently, the need for efficient policies that promote growth in the agricultural sector has been reaffirmed in the recent Malabo declaration presented by the African Union in 2014. Pledging to end hunger in Africa by 2025, it outlines ambitious targets such as doubling productivity and tripling intra-regional trade in agricultural products.

Maize represents the principal staple in Eastern and Southern Africa (ESA) and consequently it has been prioritised in much of the historic agricultural policy initiatives. Despite international pressure to liberalise markets, the need to stabilise prices at tolerable levels has been offered as justification for continued intervention in the sector. Contrary to these objectives however, observed volatility over the past decade has often been higher in markets where governments intervene most actively and with

few exceptions, maize prices in the region remain high in the global context. As such, literature evaluating policies in the region has questioned the efficiency of historic interventions in achieving stated objectives.

Most of the policy analysis in the region to date has been retrospective in nature and focused in specific countries where policies have been employed. As the region moves toward implementation of the ambitious targets outlined in the Malabo declaration, this study presents a partial equilibrium simulation model as a tool for forward looking, region-wide analysis of policy options prior to implementation. After evaluating price transmission between different markets in the region, it raised concern regarding the mismatch between the structure of maize markets in ESA and the traditional structure of partial equilibrium models. Underpinned by the law of one price, such models are typically non-spatial, relying on pooled net trade with a single representative world price transmitted to domestic markets through price transmission elasticities. This implies that trade elasticities are infinitely large, while a number of factors such as the time required to exploit arbitrage conditions, policy implementation, infrastructural restraints and imperfect information point to the need for finite elasticities.

Maize markets in the region remain isolated from the global market and, with the exception of yellow maize in South Africa, the bulk of trade occurs within the region. This results in complex interactions between multiple regional markets, but limited interaction with the world reference price. Prices in any one country are influenced not only by domestic supply and demand dynamics, but also by availability of tradable product (mainly non-GM white maize) in a number of potential trading partners. Hence any model utilised for forward looking policy analysis should incorporate this combination of factors. The model outlined in this study specified a system of behavioural trade flow equations based on spatial arbitrage conditions and includes threshold variables that render trade-flow more elastic when breached. Hence it accounts for non-linearity and multiple regimes identified in price transmission analysis, which have largely remained absent from simulation models with the ability to project trade flow into the future under alternative assumption.

The model applied in this study was shown to provide a more accurate representation of prices in ESA through a number of validation tests. Firstly, a range of statistical

measures related to goodness of fit suggested that it improved the accuracy of simulating historic prices from 2013 – 2016 relative to a traditional price linkage approach. It was also shown to simulate a plausible outlook for maize prices in ESA over a ten-year horizon and provided responses to simple fluctuations in world prices and domestic supply that are more in line with literature and prior expectation. Furthermore, application of historic volatility in domestic yield levels and world prices resulted in an improved replication of past price volatility in the trade-linkage model relative to traditional price linkage approaches.

Application of the modelling framework to the simulation of two different policy related future scenarios provided a final validation of its usefulness to answer relevant questions. In a situation where domestic supply is reduced by climatic variation, imposition of export controls in Zambia were shown to have the desired effect of reducing domestic prices for consumers, but the loss to producers outweighed the gain to consumers resulting in a net loss to society. Conversely, accelerated productivity gains in Tanzania were shown to provide a net benefit by reducing the price of maize for consumers. While the negative impact of lower prices on producers was noted, it was partially offset by higher output volumes and outweighed by consumer gains.

The study's contribution is therefore twofold: Firstly, it provided empirical evidence of the benefits attained from prioritising long-term productivity gains over short term reactions to inherently volatile prices. Secondly, it validated a tool for future policy analysis that can be applied in support of strategic decision making. The model structure essentially allows pricing to switch not only between import parity, export parity and autarkic regimes, but also between different markets as trade fluctuates. As such, it resembles actual market conditions more closely and contributes to narrowing the gap between retrospective econometric analysis of price transmission and the simplified structure of simulation models often used for *ex ante* analysis.

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# ACRONYMS

| | |
|---|---|
| ADF | Augmented Dickey Fuller |
| AGRA | Alliance for a Green Revolution in Africa |
| AIDS | Almost Ideal Demand System |
| ARDL | Autoregressive Distributed Lag |
| AU | African Union |
| BIC | Bayesian Information Criterion |
| CAADP | Comprehensive African Agricultural Development Program |
| CES | Constant Elasticity of Substitution |
| CGE | Computable General Equilibrium |
| COMESA | Common Market for Eastern and Southern Africa |
| EAC | East African Community |
| ECM | Error Correction Model |
| ESA | Eastern and Southern Africa |
| FAO | Food and Agriculture Organization of the United Nations |
| FAPRI | Food and Agricultural Policy Research Institute |
| FEWSNET | Famine Early Warning Systems Network |
| FISP | Farm Input Support Program |
| FRA | Food Reserve Agency |
| GAEZ | Global Agro-Ecological Zones |
| GDP | Gross Domestic Product |
| GIEWS | Global Information and Early Warning System on Food and Agriculture |
| GM | Genetically Modified |
| GMB | Grain Marketing Board |
| GTAP | Global Trade Analysis Project |
| IFPRI | International Food Policy Research Institute |
| IMF | International Monetary Fund |
| ITC | International Trade Council |
| KPSS | Kwiatkowski Phillips Schmidt Shin |
| LOP | Law of One Price |
| MAE | Mean Average Error |

| | |
|---|---|
| MD | Modified Index of Agreement |
| MDG | Millennium Development Goals |
| MIRAGE | Modeling International Relationships in Applied General Equilibrium |
| mNSE | Modified Nash-Sutcliffe Efficiency |
| NAAIAP | National Accelerated Agricultural Inputs Access Program |
| NAIVS | National Input Voucher System |
| NCPB | National Cereals and Produce Board |
| NEPAD | New Partnership for Africa’s Development |
| NFRA | National Food Reserve Agency |
| OECD | Organization for Economic Cooperation and Development |
| PETS | Partial Equilibrium Trade Simulation Model |
| PP | Phillips Peron |
| ReNAPRI | Regional Network of Agricultural Policy Research Institutes |
| RMSE | Root Mean Square Error |
| SADC | Southern African Development Community |
| SAFEX | South African Futures Exchange |
| SSA | Sub-Saharan Africa |
| SUR | Seemingly Unrelated Regression |
| TAR | Threshold Autoregressive |
| UN | United Nations |
| USA | United States of America |
| USDA | United States Department of Agriculture |
| VAT | Value Added Tax |

# 1. INTRODUCTION

## 1.1 Background

The establishment of the Millennium Development Goals (MDG’s) in 2000 by member states of the United Nations (UN) initiated unprecedented efforts globally towards the eradication of extreme poverty and hunger. As the largest recipient of food aid in the world, Africa was prioritized, leading to a number of policy responses in the region. The African Union (AU) committed to the revitalisation of the agricultural sector in its Maputo declaration on agriculture and food security and outlined the Comprehensive African Agriculture Development Program (CAADP). With its main objective of reduced poverty and improved food security through an agriculture led development strategy, CAADP was prioritized through commitments to allocate at least 10% of national budgetary expenditure towards its implementation within 5 years (African Union, 2003). More recently, the Malabo declaration on accelerated agricultural growth recommitted to the CAADP process of agriculture-led growth as a strategy towards achieving food security, maintaining the earlier budgetary commitments and pledging to end hunger in Africa by 2025 (African Union, 2014).

Despite the commitments and actions by the AU, reflection on the progress towards achieving hunger reduction goals globally by the UN (2015) highlights slow overall progress in Sub-Saharan Africa (SSA). Rapid population growth, which exceeded any other region in the world over the past decade, has been offered as one of the reasons for slow progress. Yet the success achieved in specific countries characterized by stable political conditions, growing economies and expanding agricultural sectors suggests that appropriate policies can improve food security, despite rapid population growth. With populations projected to continue expanding (International Monetary Fund, 2016), the question of who will produce Africa’s food requirement remains relevant. If Africa is to produce enough to supply food to its own growing population, there is an undisputed need for efficient policies that enable and promote growth in the agricultural sector.

As the principal staple in most countries within Eastern and Southern Africa (ESA), the availability and affordability of maize has been concomitant with food security in the region. Its nature as a strategic political crop has also prioritised the maize sub-sector from a policy perspective. Despite the international drive towards liberalization, the perceived need to stabilise prices and supply has been offered as justification for the continued government intervention in maize markets across ESA (Minot, 2014; Jayne & Tschirley, 2009). It has been argued that in Africa in particular, interventions that manage volatility will reduce price risks for multitudes of consumers that spend a large share of their incomes on food products. At the same time, such interventions prioritise the sustainability of the substantial share of the population that depends on agriculture for their livelihood (Minot, 2014).

Historically such interventions have however been highly discretionary and unpredictable, often characterised by the sudden implementation of trade controls, unanticipated changes to tariff policy and inconsistent pricing policies for government purchases. The unpredictability and ad-hoc nature of government activity in markets has resulted in additional risks and costs for the private sector, impeding investments that would improve access to markets and services for multitudes of small scale producers. Consequently, it has not been effective in supporting agricultural productivity growth in the region (Jayne & Tschirley, 2009) and contrary to the stabilisation objectives, observed volatility over the past decade has been higher in markets where governments intervene most actively (Minot, 2014; Jayne 2012; Chapoto & Jayne, 2009). It has been noted that the consistent application of strategic grain reserves has been successful in stabilising prices, but at higher average price levels (Jayne, Myers & Nyoro, 2008, Mason & Myers, 2013) and at significant cost to government.

Much of the historic policy focus has been centred on improved availability and reduced volatility, but the concept of food security also relates to affordability and with few exceptions, maize prices in the ESA region remain high in the global context. Figure 1.1 illustrates that domestic prices tend to be lower in countries that export relatively consistently, such as South Africa and in recent years Zambia and Uganda. These net exporting countries also present the only cases where domestic prices have dropped below the representative world price. In consistent deficit markets, prices have tended to be much higher; over the past decade prices in Zimbabwe have averaged almost 50% above South African levels, reaching a high of 131% in 2005, and almost 21% above Zambian levels, reaching a high of 35% in 2005. Similarly, prices in Nairobi, Kenya have averaged approximately 27% and 26% above exporting regions in Uganda and Tanzania respectively, with the premium peaking at 71% and 45% respectively.

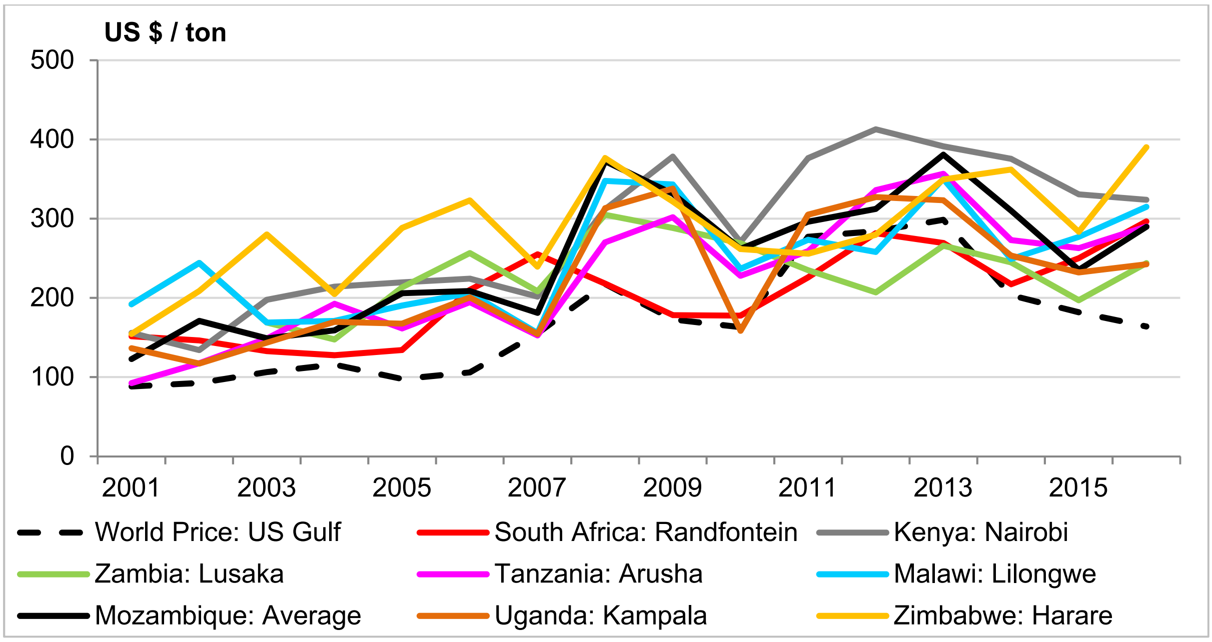

**Figure 1.1: Maize wholesale price levels: 2000 - 2016**
*Source: Compiled from FAO-GIEWS (2017)*

Maize markets in the region are isolated from the global market (Baffes, Kshirsagar & Mitchell, 2015; Baquedano & Liefert, 2014; Minot, 2011), partly due to high transportation costs and the preference for white maize that is free of genetically modified (GM) technology, which limits procurement options in the global market. Consequently, intra-regional trade becomes increasingly important and apart from South Africa, which imports significant volumes of yellow maize for use in the animal feed market in deficit periods, on average less than 10% of total imports have originated from outside of the region over the past five years (ITC, 2016). Given the prevalence of informal trade within the region (FEWSNET, 2016), the actual share is likely even smaller than that computed from the officially reported trade data. Whereas South Africa represented the main surplus producer into the region for many years, trade-flow patterns have evolved and imports are now sourced from multiple countries in the region. Kenya for instance imports significant quantities from Uganda and Tanzania, whilst Zimbabwean imports typically originate from South Africa and Zambia, depending on relative prices and trade policies (Figure 1.2). By implication, market linkages are increasingly complex with availability in any one country possibly influenced by multiple others.

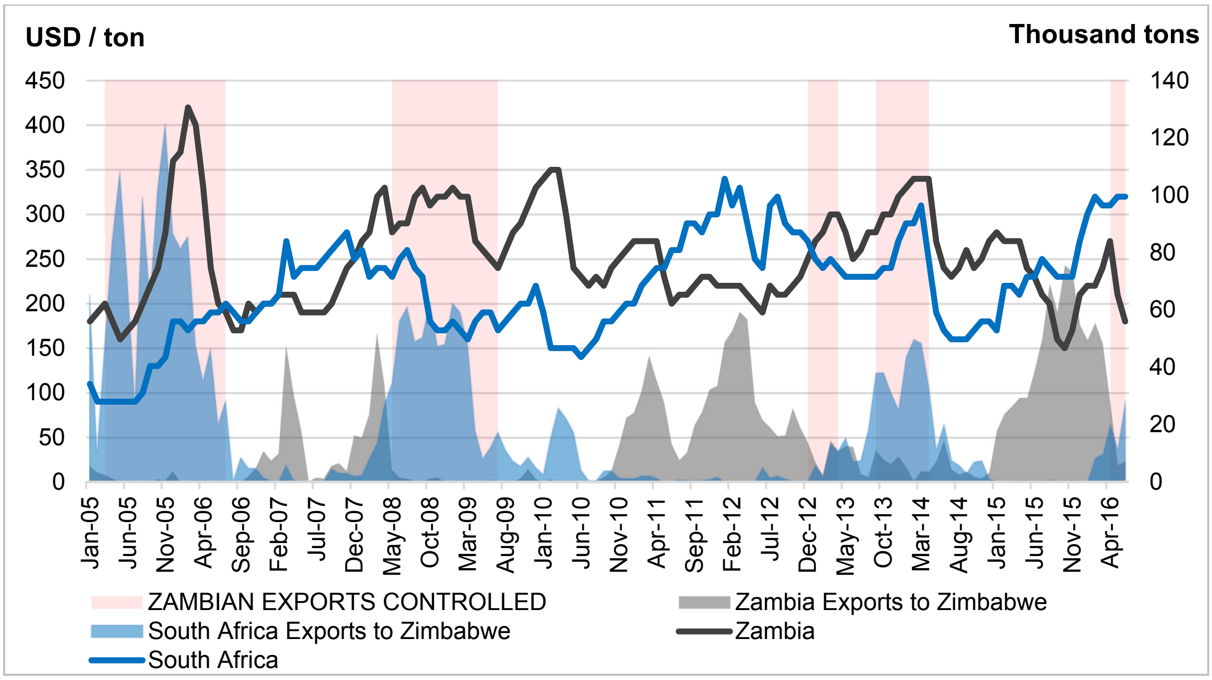

**Figure 1.2: Zimbabwean maize imports from Zambia and South Africa, with relative wholesale prices in Randfontein and Lusaka and export control periods in Zambia**
*Source: Compiled from ITC Trademap (2017), FEWSNET (2016), Porteous (2012)* and press releases.

The sharp increase in commodity prices globally post-2006 sparked renewed interest in agricultural markets and the policy instruments used to influence them. Particularly in import reliant developing regions such as ESA, the focus has related to evaluating the extent to which higher and more volatile world prices transmitted into domestic markets (Minot, 2014). Findings consistently implied infrequent co-integration between world and domestic markets for maize in particular (Versailles, 2012; Baffes *et al*. 2015; Minot, 2011) and whilst global markets were a contributing factor, the largest proportion of maize price volatility experienced in ESA markets over the past decade is attributed to domestic supply shocks (Minot, 2014). The inherent uncertainty associated with climate variability and the suggestions that changing climatic conditions will lead to increased variability in production levels in Africa going forward (Schlenker & Lobell, 2014) implies that policy makers could be faced with increasingly volatile markets. Given the demand from growing numbers of consumers in the region, governments cannot afford to take a casual approach (Jayne, 2012) and in light of the mixed success of historic policy interventions, the need for forward looking quantitative analysis that would inform future policy discussions becomes increasingly important.

A number of quantitative techniques have emerged for the evaluation of increasingly complex agricultural and trade related policies globally. The application of multiple models reflects differences in objectives and the resulting model structure, aggregation levels and data requirements (Van Tongeren, Van Meijl & Surry, 2001). Furthermore, quantitative analysis has been approached with two distinctly different strategies: *ex ante* and *ex post* analysis. *Ex post* analysis relates to retrospective policy models designed to quantify historical policy impacts. Econometric techniques are applied to evaluate the impact that historic policies have had on markets, or alternatively to indicate what the world might have looked like had specific policies been implemented in an historical base period (Abler, 2007; Teh & Piermartini, 2005). Arguing that historic implications related to the efficiency of different policies should guide decisions on future policy alternatives, various econometric techniques have been applied successfully to retrospective policy evaluation. Price transmission analysis has proven popular in evaluating spatial market efficiency, whilst gravity models have been applied successfully to answer trade liberalization questions. Despite its undeniable contribution, *ex post* analysis remains somewhat limited by its retrospective nature and consideration of policies prior to implementation also requires *ex ante* analysis.

Projection models used for *ex ante* analysis consider alternative scenarios of future outcomes and require several conditioning assumptions related to relevant exogenous variables (Abler, 2007; Teh & Piermartini, 2005; Van Tongeren *et al.* 2001). Such models have become increasingly popular tools to inform decision making and have many advantages, the greatest of which is arguably the ability to quantify the effects of different policy options or other possible scenarios prior to implementation. Simulation models have been applied successfully by international institutes such the Food and Agriculture Organization (FAO) of the UN, the Organization for Economic Cooperation and Development (OECD), the European Commission, the International Food Policy Research Institute (IFPRI) and the Food and Agricultural Policy Research

Institute (FAPRI). Whilst such models have proven useful for market analysis, price forecasts and strategic policy evaluation (Poonyth, Van Zyl & Meyer, 2000), they are by no means perfect. Binfield, Adams, Westhoff and Young (2002) indicate that models are simplifications of reality and as some factors are not incorporated into these models, even the best models can fail. Soregaroli and Sckokai (2011) argued, however, that the structure and characteristics of these models are often too simplified to represent the complexities of agricultural markets. Whilst simplifying assumptions are synonymous with quantitative modeling techniques, it is essential that model specification reflects the reality of price formation within the market, given its influence on the accuracy and predictive power of such models (Meyer, Westhoff, Binfield & Kirsten, 2006). In this regard, the extent to which complex price formation mechanisms and regional interactions between markets have been incorporated in simulation models of the agricultural sector in the African context is highly questionable.

Partial equilibrium models typically used for predictive purposes and trade policy simulation in the agricultural sector are traditionally non-spatial. The assumption of homogeneous products supports the pooled market approach (Witzke, Britz & Borkowski, 2011) and while different model closure options allow flexibility in price formation structure, failure to account for spatial trade-flow information allows these models to capture the extent to which markets are interwoven only imperfectly. Despite significant differences in price levels between countries and regions (Figure 1.1), a single representative world price is usually assumed. This limits detailed trade policy analysis, as the increasing prevalence of preferential trade agreements results in trade-related policies often being applied on a bilateral basis (Van Tongeren *et al.,* 2001).

Direct price linkages from a single representative world price are often justified by the law of one price assumption, yet Versailles (2012) notes that the violation of the law of one price is one of the most enduring stylised facts in international pricing literature and imperfect price transmission significantly decreases export demand elasticities (Bredahl, Meyers & Collins, 1979). Whilst able to account for imperfect price transmission through imposed elasticities, direct price linkages limit the impact of domestic supply shocks to trade volume fluctuations, implying no domestic price effect. This stands in direct contrast to findings that domestic supply fluctuations have been responsible for the bulk of volatility in the region (Baffes *et al.,* 2015; Minot, 2014; Minot, 2011). It also contrasts actual price movements in 2016, when a regional drought in Southern Africa resulted in sharp price increases across all Southern African countries, when a direct price linkage approach would have modelled declining prices in line with the world reference price, which decreased by 4% year on year.

While it could be argued that the linear price transmission equations in net trade models summarises spatial arbitrage conditions as long as there are no switching regimes (Witzke *et al.,* 2011), time-series analysis of spatial market efficiency suggests that switching regimes are prevalent. Given the frequency of government intervention in these markets, switching regimes are particularly relevant to the ESA region (Burke & Myers, 2014; Myers & Jayne, 2012; Traub, Myers, Jayne & Meyer, 2010) and hence an assumption of linear price transmission is questionable.

This study postulates that within maize markets in ESA, policies impact countries beyond where they are applied and evaluation of policy alternatives should therefore be considered from a regional perspective. As the region moves towards implementation of the ambitious targets outlined in the Malabo declaration, it aims to evaluate the impact of increased productivity, as well as trade control policies, on prices and trade-flows in the region. The proposed simulation model accounts for non-linearity in price transmission within multiple trading regimes, as well as the complex, multiple market interaction implied by the role of intra-regional trade. Thus it allows for detailed policy inclusion and instead of considering single countries in isolation, enables simulation and quantification of the region-wide impact of discretionary trade policies on prices and trade-volumes.

## 1.2 Problem statement

The importance of quantitative policy analysis has been well stated. The abundance of literature related to the historic impact of input support programs (Dorward & Chirwa, 2011; Ricker-Gilbert, Jayne & Chirwa, 2011), discretionary trade policies (Diao & Kennedy, 2016; Baffes *et al*., 2015; Porteous, 2012; Chapoto & Jayne, 2009; Haggblade, Jayne, Tschirley & Longabaugh, 2008) and the participation of marketing boards (Chapoto & Jayne, 2009; Jayne & Tschirley, 2009) in various countries in ESA suggest that quantitative analysis has not been lacking in the region. However existing analysis has been retrospective in nature and focused on specific countries, whilst the prevalence of intra-regional trade suggests that quantitative analysis considering any single country in isolation would provide an incomplete picture, ignoring impacts on neighbouring countries. A simple graphical representation of wholesale white maize prices in Zambia and Zimbabwe in Figure 1.3 suggests that the implementation of export bans in Zambia may impact price movements in both Zambia and Zimbabwe. Hence analysis should not be limited to individual countries, but rather considered from a regional perspective. Some cross-country comparisons have been forthcoming, but evaluation of the impacts that policy choices in any single country has on neighbouring countries in the region has been lacking.

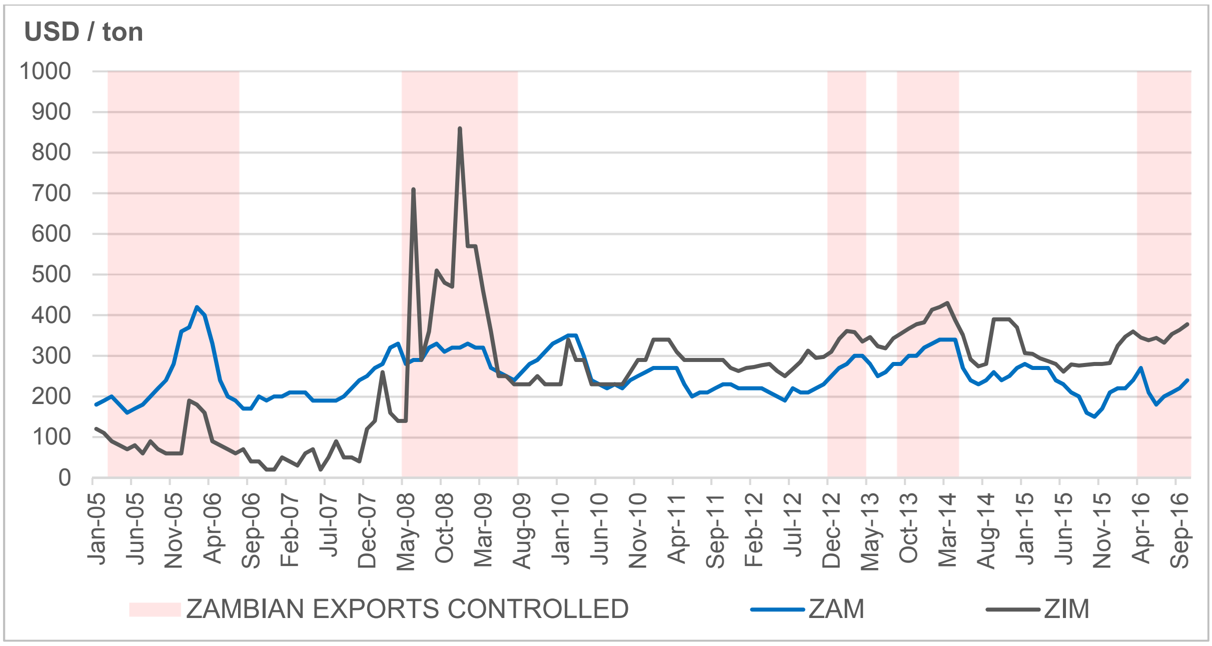

**Figure 1.3: Wholesale white maize prices in Zambia and Zimbabwe during periods of open borders and export control: January 2008 - October 2014**
*Source: FAO-GIEWS (2017), Porteous (2012) and various press releases.*

Despite the illustrated need to consider the wider regional effect of policies, the extent of market integration between different countries in the region has not been well quantified. Limited literature does point to co-integration between South Africa and Zambia as well as South Africa and Mozambique under certain regimes (Myers & Jayne, 2012; Traub *et al*., 2010), whilst Baffes *et al*. (2015) also suggest co-integrated movement of prices in Kenya and Tanzania. Trade-flow patterns, as well as simple pairwise correlations (Table 1.1) would suggest that co-integrated relationships are likely between other country pairs as well. The extent of correlation between various markets differs, however and the magnitude and speed of price transmission between the various markets in the region, as well as the impact of trade and policy application on these parameters remains unclear.

Econometric analysis of price transmission has proven useful in understanding the total impacts of a combination of past policies through price relationships. The lack of explicit inclusion of specific policies however, does not allow the impacts of different policy responses to be separated. The complex transmission patterns described are yet to be integrated into a simulation modeling framework that can be applied for *ex ante* analysis and is able to account for intricate policy combinations and shifting fundamentals in a dynamic system. A single exception is the regime-switching mechanism introduced into a partial equilibrium model of the South African agricultural sector by Meyer *et al*. (2006), which allowed for alternative model closure under different market regimes. While this represented a significant improvement to the model in terms of its interaction with the world price, it still fails to account for the interaction with multiple markets in the ESA region, which would not be evident in world price dynamics.

**Table 1.1: Linear correlation matrix for maize prices in ESA**

| | South Africa: Randfontein | Kenya: Nairobi | Zambia: Lusaka | Tanzania: Arusha | Malawi: Lilongwe | Mozambique : Maputo | Uganda: Kampala | Zimbabwe: Harare |
|---|---|---|---|---|---|---|---|---|
| South Africa: Randfontein | 1 | 0.69 | 0.48 | 0.73 | 0.48 | 0.68 | 0.69 | 0.56 |
| Kenya: Nairobi | | 1 | 0.53 | 0.95 | 0.74 | 0.86 | 0.93 | 0.64 |
| Zambia: Lusaka | | | 1 | 0.63 | 0.85 | 0.75 | 0.65 | 0.80 |
| Tanzania: Arusha | | | | 1 | 0.82 | 0.90 | 0.94 | 0.75 |
| Malawi: Lilongwe | | | | | 1 | 0.87 | 0.86 | 0.73 |
| Mozambique: Maputo | | | | | | 1 | 0.91 | 0.74 |
| Uganda: Kampala | | | | | | | 1 | 0.74 |
| Zimbabwe: Harare | | | | | | | | 1 |

Despite the historic focus on retrospective analysis, forward looking simulation models that cover the ESA region are not completely absent. The region is included in a number of models with global coverage and particularly Computable General Equilibrium (CGE) models such as Global Trade Analysis Project (GTAP) and Modeling International Relationships in Applied General Equilibrium (MIRAGE) have been applied successfully. These CGE models have many advantages, which include consistency with economic theory and the ability to capture the inter-linkages between various sectors of the economy explicitly. The spatial nature of these models, which account for bilateral trade-flows between different countries, typically in the form of Armington elasticities, has made them popular in trade policy analysis, particularly when multiple sectors are involved. However their complex nature and economy wide coverage limits the extent of disaggregation within sectors, which can obscure important underlying relationships. High levels of aggregation also limit detailed policy inclusion within specific sub-sectors which, combined with their data intensiveness and predominantly static nature has been the source of most criticism related to CGE models (Teh & Piermartini, 2005; Van Tongeren *et al*., 2001). Price information remains weak in these models and application to complex, commodity specific policy evaluation has been limited as a result, with less aggregated partial equilibrium models the preferred alternative.

Within the partial equilibrium framework, optimization decisions are not explicitly modeled, relying instead on a reduced form approach to model supply and demand interactions within specific sectors. Consideration of a single sector in isolation from the rest of the economy allows for a much more detailed representation of policy and price formation, yet within the ESA region, much of this advantage remains unexploited. Existing partial equilibrium models have either a country specific (Mapila, Kirsten, Meyer & Kankwamba, 2013; Kapuya, Meyer & Kirsten, 2013; Meyer, 2006; Poonyth *et al*., 2000), regional (Laborde & Tokgoz 2015) or global (OECD & FAO 2015) coverage. Regional dynamics can be considered within the Partial Equilibrium Trade Simulation (PETS) model constructed by IFPRI (Laborde & Tokgoz, 2015), or the global Aglink-Cosimo model (OECD & FAO, 2015). Both these models are multi-region, multi-sector, dynamic recursive models and while model structures differ significantly, they share the same weakness in considering price impacts. Use in specific maize related questions is also limited by product aggregation.

Within Aglink-Cosimo, the assumption of homogeneous goods and the law of one price results in a non-spatial model based on pooled net trade. The PETS model on the other hand accounts for bilateral trade-flows based on product heterogeneity by origin (Armington, 1969), yet the model is focused on the demand side and supply is assumed to be infinitely elastic, which implies that producer prices do not change and consumer prices change only in response to changing tariffs. The lack of detail regarding price levels and price formation limits the use of the model in measuring price impacts, whilst the 2007 base-year loses the dynamic changes that have occurred in agriculture across ESA over the past decade. Given the policy focus in the region on maintaining prices at tolerable levels (Jayne, 2012), the simulation of price impacts is important in evaluating policy options.

Given the lack of readily available data, simplifying assumptions related to pricing in partial equilibrium models is not new. Within typical net trade models, the law of one price assumption often results in domestic prices specified through direct price linkage equations based on transmission elasticities (Witzke *et al.*, 2011). This is justified in countries that are considered too small to influence world markets, however within maize markets in ESA, limited trade outside the region suggests that price dynamics and price transmission should be considered from a regional instead of a global perspective. Most countries in the region would be considered small in the global context and would therefore not be expected to influence world price dynamics, but the majority of countries are large enough to influence regional supply and demand conditions within the isolated white maize market. Consequently, domestic supply and demand dynamics becomes increasingly important for price formation, as changes in excess supply or demand would potentially impact domestic price levels, as well as a number of trading partners in the region.

Direct price linkage to the world price through price transmission elasticities fails to capture such impacts, limiting the influence of domestic supply and demand shocks to trade volumes and implying that domestic supply and demand shocks do not affect prices. Within this modeling structure, increased productivity will not affect prices, which does not seem plausible when the evolution of the Zambian maize sector in particular is considered. Increased production over the past decade has moved it from a net importer to a consistent surplus producer in the region, resulting in a significant decline in the market price for commercial maize that would not have been captured in a price-linkage model. Similarly, a substantial productivity increase in any other country in the region could change its net trade position, with significant potential implications for domestic market prices.

Within ESA, the need to maintain maize prices at tolerable levels has been demonstrated by policy responses to the 2007/2008 food price crises (Jayne, 2012). Current simulation models that could be applied to agricultural policy analysis in the region (such as Aglink-Cosimo and PETS) were not designed to quantify price specific impacts. Consequently, the inclusion of detailed pricing dynamics is limited. Failure to account for complex interactions between multiple markets in the region and explicit policy influences suggests that the true price formation mechanisms are neglected in the current framework. The mismatch between the structure of maize markets in ESA and the structure of these simulation models questions their predictive power and consequently also the credibility of policy simulations conducted with them. The prioritization of the maize sector in this study suggests that a partial equilibrium model is better equipped for detailed policy inclusion, yet structural changes to the typical partial equilibrium modeling setup will need to be made to capture the salient market features associated with the region.

## 1.3 Research objectives and justification

The purpose of the study is to provide empirical evidence in support of the debate related to the short and long-term impacts of different policy applications and alternative future outcomes as the region moves towards the implementation of the Malabo declaration. In doing so it also aims to provide a simulation model structure that narrows the gap between knowledge on price formation derived from *ex post* price transmission analysis and the simplified structure typically assumed in existing simulation models of the region.

Given the target date of 2025 set in the Malabo declaration, policy impacts will be considered within a forward looking simulative framework, from a regional perspective rather than single country analysis. In order to quantify regional impacts, true price discovery, which includes domestic supply and demand dynamics, multiple linkages between different markets and multiple trade regimes will be incorporated in the modeling structure. To achieve this, the following specific objectives have been identified:

1) Evaluate the extent of market interaction between different countries in ESA
    a. Evaluate production and consumption trends over the past decade to contextualize market fundamentals
    b. Evaluate the evolution of trade-flow patterns over the past decade qualitatively
    c. Relate trade-flow patterns to co-integration through the identification of alternative regimes and quantification of price transmission (magnitude, speed and direction) between relevant country-pairs
    d. Consider the extent to which price transmission differs in periods when export controls are in place relative to periods with unrestricted trade
    e. Quantify the extent of price transmission between different relevant markets (cities) within each country

2) Considering the implications of the price-transmission analysis in Objective 1 for the structure of a partial equilibrium simulation model of maize markets within ESA, compare a system of behavioral trade-flow equations with equilibrium pricing and explicit policy inclusion in each country to a traditional direct price linkage approach.
    a. Evaluate alternative specifications of behavioral trade-flow equations, considering the implications of different assumptions related to product homogeneity and the impact of trade-related costs.
    b. Evaluate the effectiveness of the different model structures in simulating historic prices
    c. Evaluate the performance of the alternative modeling structures in simulating a baseline outlook
    d. Evaluate the performance of the alternative modelling structures in capturing the effect of market shocks in terms of:
        i. Price response to world price fluctuations
        ii. Price response to domestic supply shocks

        iii. Ability to regenerate historic market volatility if historic yield variations are carried forward into the projection period

3) Apply the newly introduced system of behavioural trade flow equations with equilibrium pricing from objective 2 to simulate different future outcomes and validate the results for consistency with economic theory and prior expectation.
    a. Illustrate the impact of a supply shock in the Southern African region on prices and trade-flows under a scenario where open border policy is maintained as opposed to a scenario where export controls are imposed in response to the supply shock.
    b. Illustrate the impact of improved productivity growth in Tanzania relative to the past decade on price levels and trade-flow patterns across the ESA region. Tanzania is chosen for this illustration based on it cultivating the largest area to maize of all the countries in the modelled region, as well as its potential to increase maize production thereby becoming a consistent exporter in East Africa.
    c. Given high transportation rates and its trade inhibiting impact, illustrate the impact of reducing transportation rates in the scenario where productivity growth in Tanzania is accelerated relative to the past decade

The abundance of literature related to the evaluation of agricultural policies in Africa continues to be dominated by retrospective, *ex post* analysis. Various authors evaluate the effects of market reform (Jayne & Jones, 1997; Jayne, Rubey & Tschirley, 1995), spatial market efficiency (Brenton, Portugal-Perez & Regolo, 2014; Myers & Jayne, 2012; Versailles, 2012; Minot, 2011; Traub *et al.*, 2010; Tostao & Brorsen, 2005) and price volatility (Minot, 2014; Jayne, 2012; Chapoto & Jayne, 2009; Byerlee, Jayne & Myers, 2006), yet the use of *ex ante* simulation of policy alternatives, that has proven very successful in the global context, remains limited. The reluctance towards simulation modeling may be nested in the mismatch between observed pricing behavior and the level of aggregation and assumptions typically associated with projection models. Such models will always remain simplifications of reality, but significant improvements can be made to the price information and dynamics contained in the structure of current simulation models of the region.

The comprehensive evaluation of the co-integrated nature of maize markets within ESA and subsequent incorporation of market linkages into a partial equilibrium modeling framework is used within this study to incorporate complex policies more explicitly. *Ex post* analysis has been critical of discretionary trade policies, hence the model will be used to illustrate *ex ante*, the different market expectations under a scenario where export bans are imposed in response to drought conditions. The system is also applied to illustrate the impacts of short term trade control implementation relative to long term productivity gains on maize prices in the region.

Whilst the quantification of trade policy impacts across the region as opposed to focused analysis within single countries contributes to the literature on policy effects, the modeling tool represents a significant structural improvement that can be implemented in a scenario when multiple markets interact simultaneously to influence prices. This is particularly appropriate for maize markets in the region, where trade in the global market is limited and intra-regional trade is important in meeting demand. Given the association with food security and the historic prioritization of maize from a policy perspective within the ESA region, the improved simulation of price formation dynamics in the region also provides an *ex ante* policy analysis tool that can be expanded to include more commodities and countries for future policy simulations in a very dynamic region.

### 1.4 Conceptual framework

In order to quantify the region-wide impact of maize policies in ESA, a number of questions will need to be answered in this study. The conceptual framework of how these questions will be answered and how they relate to each other is presented in Figure 1.4.

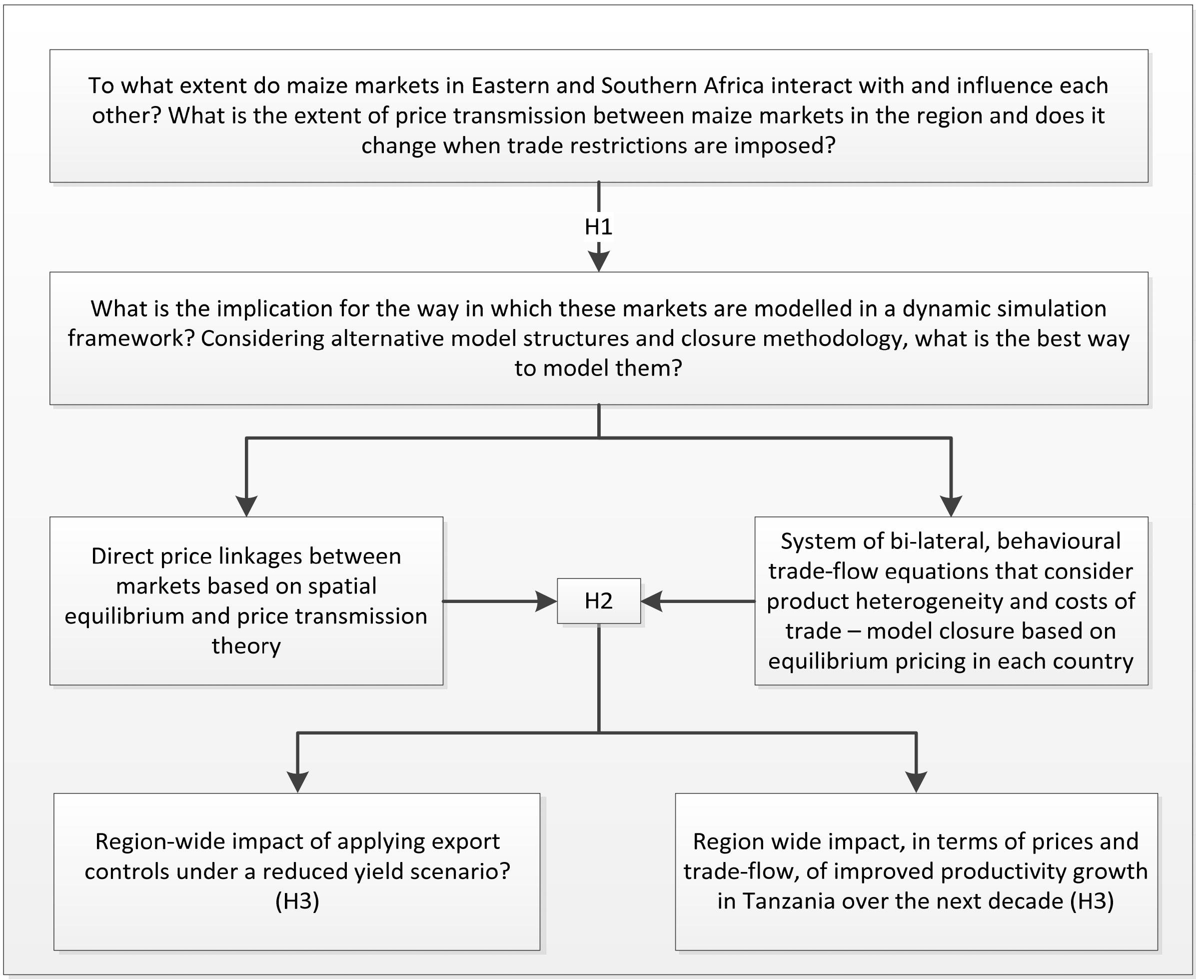

**Figure 1.4: Conceptual framework for the analysis**

## 1.5 Statement of hypothesis

Section 3 outlined multiple objectives within the study and consequently, in line with the conceptual framework illustrated in Figure 1.4, various hypotheses will be considered.

### 1.5.1 Hypothesis 1: Regional market interaction

Despite the weak co-integration of maize markets within Eastern and Southern Africa in the global maize market (Baffes *et al.,* 2015; Minot, 2011), simple pairwise correlation coefficients suggest that prices in different countries within the ESA region are co-integrated. This study hypothesizes that:

a) Regional co-integration exists between markets where trade-flow typically occurs
b) Price transmission is not linear, instead multiple regimes are evident with different rates of price transmission.
c) The price relationship between Zambia, Zimbabwe and South Africa will differ during periods when export controls were applied in Zambia relative to periods when trade occurred freely. Specifically:
    i. Zimbabwean prices are derived from Zambian prices during periods of open trade, but from South African prices when Zambian exports are restricted and
    ii. that price transmission is more rapid and efficient under an open trade regime.

### 1.5.2 Hypothesis 2: Model structure and validation

In evaluating the price transmission between different markets as proposed under hypothesis 1, the estimation of single parameters lends itself to statistical testing and validation. Consideration of a system of interlinked equations however presents challenges to statistical validation and consequently also to hypothesis formation (Meyer, 2006). This study proposes that a system which includes bi-lateral behavioral trade-flow equations and establishes market equilibrium within each country represents a more accurate reflection of price formation and market conditions in ESA. Therefore, it will provide more plausible projections than a system of direct price linkage between markets through the imposition of price transmission elasticities. Behavioural trade flow equations will allow for interactions between multiple markets, as well as non-linearity in price transmission between markets, achieving a similar effect to the regime-switching model introduced by Meyer *et al*. (2006).

The use of synthetic parameters does however not lend itself to statistical validation and no single test can be specified that will render the model valid or better than alternative approaches. Instead conclusions related to modeling improvements consider a number of evaluations which combine to provide evidence, albeit sometimes subjective, of plausible results. Consequently, the second hypothesis is not stated as a single proof, but rather presented as a combination of simple tests and more complex real-world scenarios. While some of these are testable and others subject to subjective evaluation, when considered in combination, they will provide evidence that the bilateral trade modeling framework is an improvement on existing price linkage approaches in terms of usefulness and plausibility. The following simple hypotheses can be specified:

a) Hypotheses assessed by subjective evaluation:

   a. The bilateral trade model will be able to generate a plausible 10-year outlook for maize prices given a set of exogenous assumptions
   b. The bilateral trade model will be able to generate a plausible 10-year outlook for maize trade-flow given a set of exogenous assumptions
   c. The bilateral trade model will capture the impact of domestic and other regional supply shocks on domestic price levels satisfactorily
   d. The bilateral trade model will allow prices in any one market to be influenced by multiple others, depending on trade volumes

b) Hypothesis assessed through statistical indicators:
   a. When both models are specified based on the same historic dataset and used to simulate prices over the same historical period, the bilateral trade model will reduce error relative to a model with direct price linkages to a single representative price
   b. When both models are specified based on the same historic dataset and historic yield and world price volatility is imposed to both models over the Outlook period, the bilateral trade model will be able to replicate historic volatility better than a price linkage approach

### 1.5.3 Hypothesis 3: Model application and policy simulations

The third hypothesis relates to the simulation of different policy alternatives over a future period, which does not lend itself to statistical validation. Instead the objective is to apply the improved model structure to evaluate the price impacts of alternative future scenarios that could not be simulated plausibly within a traditional price linkage approach. The hypothesis therefore relates to the model's ability to generate plausible simulations in examining real world issues, which represents another form of validation in itself (Meyer, 2006). Validation rests in plausibility of results and consistency with theoretical expectation; hence the hypothesis is also formulated as expectations related to the various simulations. These expectations are noted below:

a) In the event of reduced yield levels, the implementation of export controls will reduce prices in the country where they are employed, whilst increasing prices in neighbouring countries. Thus, in the country of application, consumer welfare is improved at the expense of producer welfare, yet in neighbouring countries the opposite will be true. This will result in some production shifting to neighbouring regions in subsequent years

b) Increasing the rate of productivity growth in Tanzania over the Outlook period relative to the past will result in a significant decline in price levels in Tanzania, whilst also increasing trade flows to Kenya and thereby reducing price levels in Kenya and Uganda. Impacts on other Southern African countries will be limited due to distance between markets and high transportation costs, which continue to inhibit trade

c) In a scenario of accelerated productivity growth in Tanzania, a reduction in transportation rates will increase intra-regional trade generation

### 1.6 Delimitations

The study will not include all countries within ESA, but rather 8 specific ones currently included in the Regional Network of Agricultural Policy Research Institutes (ReNAPRI). Whilst policy evaluations and implications will therefore be restricted to these countries, they account for a significant share of maize production and consumption across ESA and are sufficient to illustrate the use of the model applied. Commodity coverage is restricted to the maize sector, however the methodology can be replicated to include a wider country and commodity coverage in future analysis.

### 1.7 Dissertation outline

The dissertation will be structured into three main sections, according to the main objectives and themes outlined in Section 1.3. The first, presented in Chapter 2, relates to historic market trends and regional price transmission in ESA. The second, presented in Chapters 3 and 4, relates to the implications of regional price transmission for model structure, price formation, model specification and validation. The third, presented in Chapter 5, will relate to the impact of different policy interventions and alternative future outcomes on prices and trade-flow within ESA and relate these to the stated goals within the Malabo declaration.

# 2. MAIZE MARKET INTERACTION IN EASTERN AND SOUTHERN AFRICA

## 2.1 Introduction

In ESA, the agricultural sector as a whole and maize markets in particular have evolved rapidly over the past decade. Production has expanded swiftly, trade flow patterns have changed and price formation has become increasingly complex, influenced by a multitude of factors in global, regional and domestic markets. While the purpose of this study is to provide forward looking analysis related to policy alternatives in the region, any forward-looking analysis of alternative future outcomes must first consider the point of departure. An understanding of past price relationships, as well as the impact that trade and policies have had on these relationships, is critical for the correct structure and specification of forward looking simulation models (Meyer *et al.,* 2006). Hence the purpose of this chapter is twofold – firstly to provide context and understanding related to changing market fundamentals over the past decade and secondly to add to the existing body of literature related to maize price relationships across ESA.

Despite the importance of maize within broader agricultural sectors in the region, only 5% of global maize production occurred in SSA between 2014 and 2016 (OECD-FAO, 2017). Therefore, regardless of the isolation of SSA maize markets that results from the preference for non-GM white maize and high transportation rates (Baffes *et al.,* 2015; Minot, 2011), any changes in regional maize markets must still be considered within the context of global market dynamics. For this reason, the chapter starts with a brief overview of global maize markets over the past decade, before providing a more detailed synthesis of the evolution of regional maize markets in ESA since 2006.

Following the market overview, it presents an in-depth evaluation of maize price relationships in the region, both in terms of existing literature and empirical analysis. It considers long run cointegration, price transmission and short run adjustment rates between different markets, as well as the impacts of policy application on these relationships. The quantification of past price relationships provides the understanding of price formation that underpins the proposed modelling structure and the analysis conducted with it in later Chapters.

## 2.2 Overview of the global maize market

Maize consumption globally has expanded at an unprecedented rate over the past decade. Remarkable economic growth in China supported rising demand for meat products in the most populous country in the world, which in turn stimulated the demand for animal feed. The emergence of the biofuel sector, where maize offered a popular feedstock for ethanol production added further impetus and from 2006 to 2016, world maize consumption increased by an annual average of 3.5%. Maize used for biofuel production increased by 8.8% per annum, to reach more than 17% of total maize use by 2016, from merely 9% in 2006. Maize use in the animal feed market also expanded rapidly at 2.6% per annum of a much higher base, whereas food use grew by 1.9% per annum (Figure 2.1).

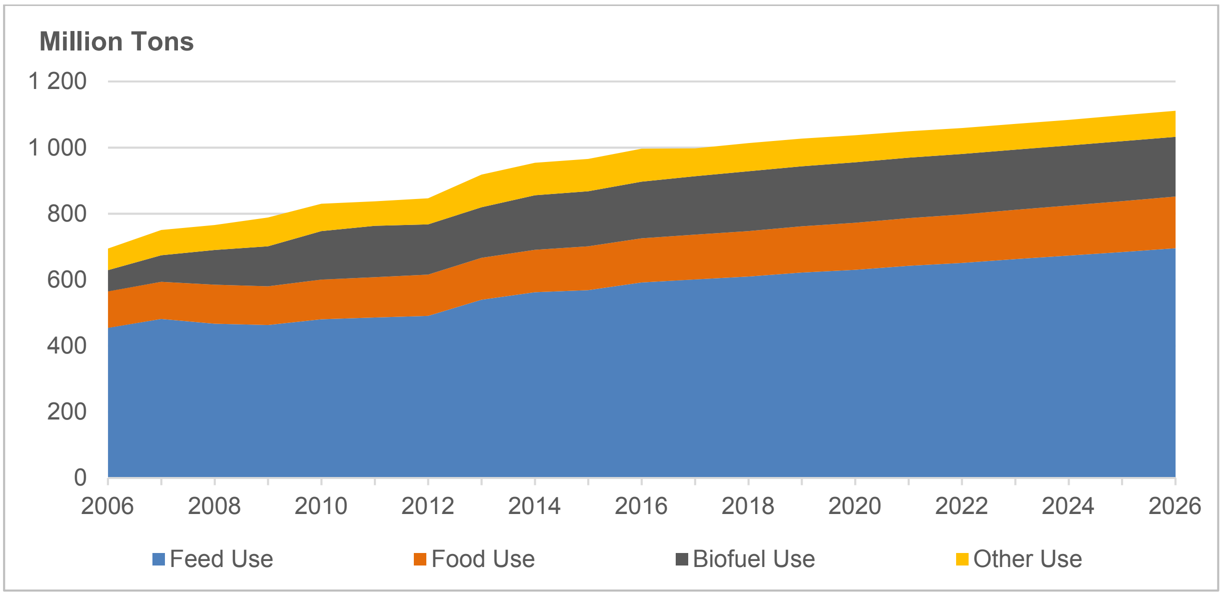

**Figure 2.1: Maize consumption in the global market: 2006 - 2026**
*Source: Compiled from OECD-FAO (2017)*

Over the next ten years, the OECD-FAO (2017) projects a significant slowdown in growth rates to 1.1% per annum. Following the rapid decline in oil prices since mid-2014, ethanol production has largely stagnated at mandated levels, with limited growth projected for the coming decade. At the same time, domestic credit limitations and the transition to a consumer driven economy have weakened the growth prospects in China. Combined with per capita meat consumption in China starting to approach the levels observed in developed economies, this slowdown in growth underpins slower meat consumption growth and consequently also feed grain imports. Despite slowing to 1.6% per annum over the coming decade, the demand for animal feed remains the strongest driver of total maize consumption going forward (OECD-FAO, 2017).

Strong demand has been an important factor behind the so-called commodity super cycle, as global maize prices shifted to new levels post 2007. This price cycle also induced substantial production growth, firstly by initiating an expansion of 1.8% per annum in the area cultivated to maize globally since 2006 and secondly by stimulating investment in technology that aided yield growth of 1.8% per annum since 2006. Consequently, production expanded by 3.6% per annum between 2006 and 2016 (Figure 2.2). In South America, both area expansion and yield gains outpaced the global average, inducing production growth of more than 5% per annum.

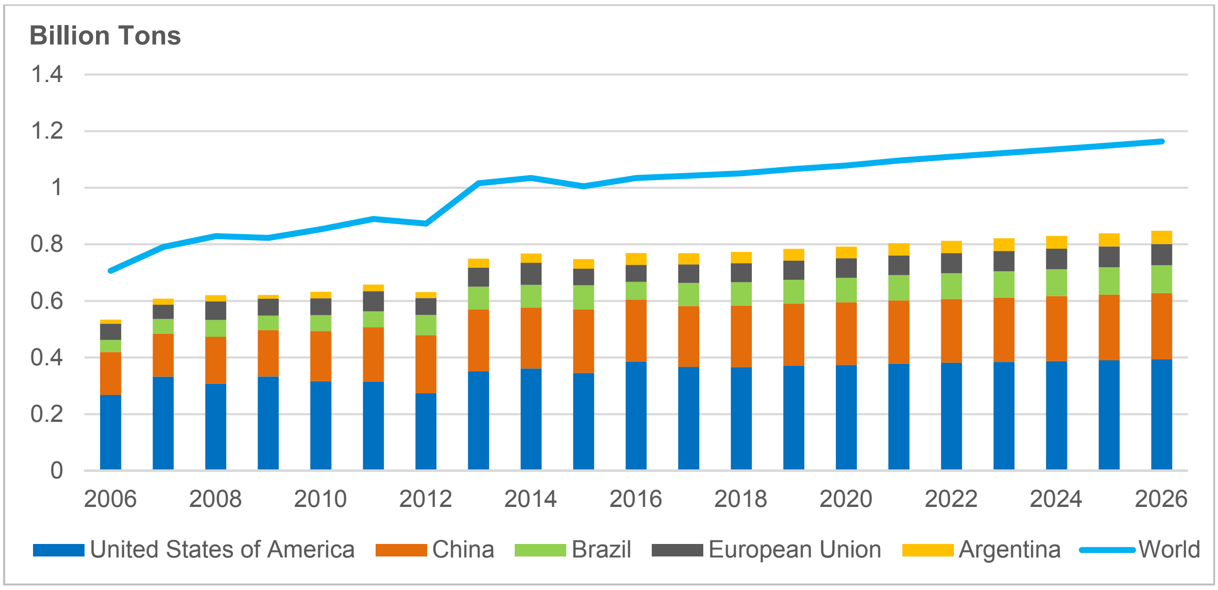

**Figure 2.2: Growth in global maize production: 2006 – 2026**
*Source: Compiled from OECD-FAO (2017)*

Over the course of the next decade, production growth is projected to slow significantly to 1.2% per annum, in line with consumption. Growth is expected to accrue from continued yield gains rather than further area expansion (OECD-FAO, 2017). Production remains concentrated in the United States of America (USA) and China, who produced almost 60% of the global maize crop in 2016, but growth in land abundant regions of South America, particularly Brazil, is expected to outpace that of the USA and China over the next decade. Consequently, a rising share of global production will originate from South America in future.

Following the drought conditions experienced in the USA in 2012, global supply has exceeded consumption for a number of years, replenishing stock levels and leading to a significant decline in prices. With ample stocks in the market, international institutes such as FAPRI (2017) and the OECD-FAO (2017) indicate that prices are expected to continue on a lower path for some time. While some recovery is expected in the medium term, prices are expected to remain well below the peaks of 2011-2013 in the absence of major supply shocks. In real terms, this implies a return to the long term declining trend.

### 2.3 Overview of maize markets in Eastern and Southern Africa

In contrast to the global market, where the bulk of maize is consumed as animal feed, maize is consumed primarily as food in ESA, where it represents the primary staple crop. It provides the foremost source of calories in the average diet accounting for approximately 25% of total caloric intake between 2013 and 2015 and average per capita consumption of 93.5kg per person in ESA was more than five times the global average (OECD-FAO, 2016).

Maize also accounted for more than 35% and 50% of total cultivated area in Eastern and Southern Africa respectively between 2013 and 2015 (OECD-FAO, 2016) and is grown by multitudes of smallholder producers across the region, who rely on it for food and income (Minot, 2014). In light of its importance, it has also been the target of numerous policy interventions, as efforts to improve food security in the region prioritised the expansion of maize production.

### 2.3.1 Maize consumption trends in Eastern and Southern Africa

Over the course of the past decade, SSA was home to some of the fastest growing economies in the world, albeit from a small base. At the same time, populations have expanded rapidly, which reduced the impact on per capita income to some extent. The rate of population growth has also resulted in a situation where, despite rapid urbanisation and the emergence of a number of mega-cities, rural populations are also still expanding. The combination of income and population growth supported an expansion of 3.8%[1] per annum in total maize consumption across ESA from 2006 to 2015. Owing to differences in both absolute income levels and the rate of income growth across countries, the relative growth rates in feed and food use differs significantly (Table 2.1).

**Table 2.1: Growth in maize consumption across ESA: 2006 - 2016**

| Country | Food use (Thousand tons) | | | | Feed use (Thousand tons) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2006 | 2015 | Abs. growth 2006-2015 | Average annual growth 2006-2015 | 2006 | 2015 | Abs. growth 2006-2015 | Average annual growth 2006-2015 |
| **South Africa** | 4489.3 | 5508.5 | 1019.2 | 1.1% | 4047.2 | 5577.2 | 1530.0 | 3.1% |
| **Zambia** | 1462.6 | 1996.5 | 534.0 | 5.6% | 50.0 | 585.8 | 535.8 | 33.3% |
| **Uganda** | 872.3 | 1777.3 | 905.0 | 8.1% | 120.0 | 390.0 | 270.0 | 11.9% |
| **Tanzania** | 2772.2 | 5268.7 | 2496.5 | 8.2% | 400.0 | 625.0 | 225.0 | 8.9% |
| **Malawi** | 2207.6 | 2557.2 | 349.6 | 2.7% | 100.0 | 249.3 | 149.3 | 5.9% |
| **Mozambique** | 1185.5 | 1289.5 | 104.0 | -1.6% | 100.0 | 209.8 | 109.8 | 11.0% |
| **Kenya** | 2795.8 | 3315.8 | 520.0 | 2.8% | 300.0 | 405.0 | 105.0 | 13.6% |
| **Zimbabwe** | 1479.6 | 1309.2 | -170.4 | -0.8% | 136.2 | 91.4 | -44.8 | -3.2% |
| **TOTAL** | 17265.0 | 23022.9 | 5757.9 | 3.4% | 5253.4 | 8133.5 | 2880.2 | 5.1% |

*Source: Compiled from ReNAPRI (2017)*

The dietary diversification associated with urbanisation and higher income levels noted by Tschirley, Dolislager, Meyer, Traub and Ortega (2013) is evident in rapid growth of more than 5% per annum in feed consumption over the past decade, which points to increased production of animal products. In countries such as South Africa, Kenya, Mozambique and Malawi, feed use has expanded, while per capita food use has remained stable or declined (Figure 2.3 and Table 2.1). At the same time, per capita maize consumption has continued to increase in Zambia, Uganda and Tanzania. In

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[1] Growth rate calculated using the least squares method.

Zimbabwe, both food and feed use has declined in the midst of troubling economic conditions.

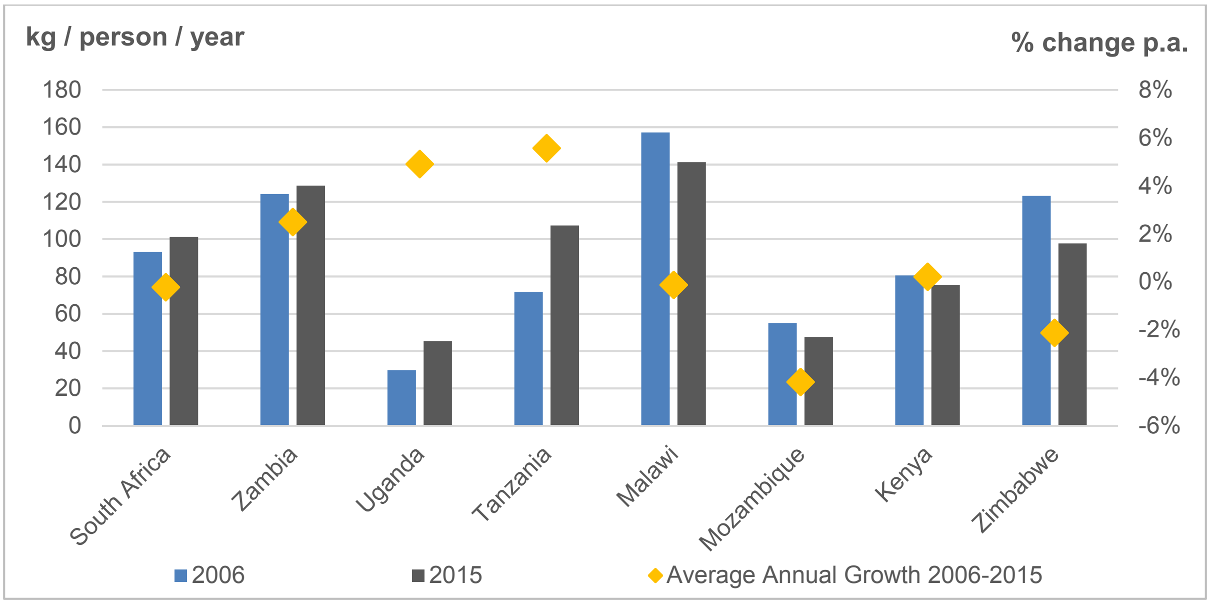

**Figure 2.3: Per capita maize consumption growth in Eastern and Southern Africa**
*Source: Compiled from ReNAPRI (2017)*

In absolute terms, growth in regional food consumption continues to outpace that of animal feed (Table 2.1). Despite evidence of dietary diversification, food consumption remains the primary driver of growth, expect for South Africa and Zambia where feed consumption is also a major growth driver. Between 2006 and 2015, more than 65% of the increase in total regional consumption was for food purposes. This number is also somewhat skewed by South Africa, evidenced by more than 75% of growth in total consumption being attributable to food use if South African consumption is not accounted for. In 2015, maize consumed as food totaled almost three times that consumed in the animal feed market.

At country level, growth in feed use exceeded that of food use in South Africa, Zambia and Mozambique, but the difference was only significant in South Africa, where intensive livestock production grew rapidly over the same period. The significant increase in maize consumed as food, combined with more limited increases and in some cases declining per capita consumption indicates that rapid population growth was an important driver of increased food consumption.

### 2.3.2 Maize production trends in Eastern and Southern Africa

Maize production in ESA has also expanded swiftly over the past decade from just over 21 million tons in 2006 in the eight countries included in the study, to more than 37 million tons in 2014. Drought conditions resulted in a decline to just over 30 million tons in 2015, but over the 10-year period, total production from the region expanded by 4.9% per annum (Figure 2.4). This growth was sufficient to outpace consumption, resulting in a positive net trade balance for the region at aggregate level from 2008 to 2014, before drought conditions in Southern Africa resulted in a small deficit in 2015. South Africa remains the largest producer in the region and despite year on year variation due to weather conditions, accounted for an average of 39% of total production over the 10-year period. Production growth has however been particularly strong in Zambia (9.7% p.a.), Uganda (8.5% p.a.) and Tanzania (8.2% p.a.).

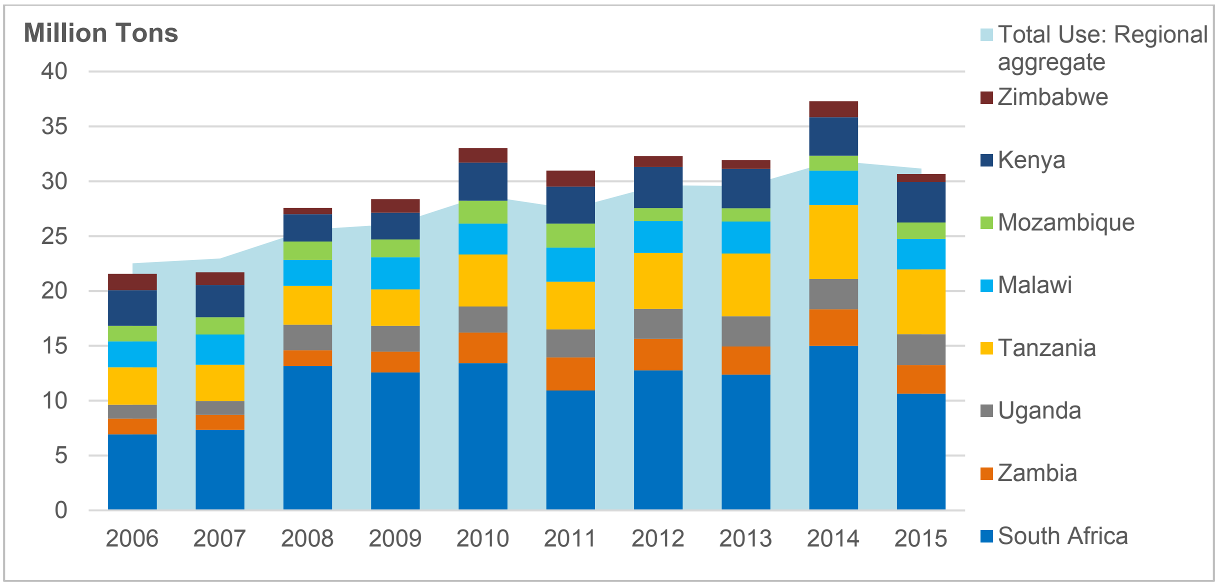

**Figure 2.4: Maize production in Eastern and Southern Africa**
*Source: Compiled from ReNAPRI (2017)*

Table 2.2 presents total growth rates achieved across the countries included in the study, as well as absolute levels at the beginning (2006) and end (2015) of the period considered. Growth is further disaggregated into area and yield components to illustrate the relative drivers of increased production across the region. In the countries that experienced the fastest total growth rates (Zambia, Uganda, Tanzania and South Africa), production was underpinned by a combination of area expansion and yield gains. The greatest area expansion occurred in Zambia and Tanzania, both of which still have land available for expansion (Chamberlain, Jayne and Heady, 2014), but Uganda, South Africa and Kenya also expanded cultivated area by more than 2% per annum. In South Africa, this growth occurred in yellow maize rather than white maize.

The greatest yield gains were achieved in Uganda (4.6% p.a.), Zambia (3.6% p.a.), Tanzania (3.2% p.a.), South Africa (2.4% p.a.) and Malawi (2.3% p.a.). Apart from South Africa however, these yield gains were achieved from a very low base and in absolute terms, only South Africa, Uganda and Zambia achieved yields of more than 2 tons per hectare by 2015. In Malawi, yield improvements were the driving factor behind production growth of 2.1% per annum, as the area cultivated to maize declined by 0.1% p.a. over the same period.

**Table 2.2: Production, area and yield growth in ESA: 2006 - 2015**

| **Country** | **Production (Thousand ton)** | | | **Area (Thousand ha)** | | | **Yield (Ton / ha)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **2006** | **2015** | **Average annual growth 2006-2015** | **2006** | **2015** | **Average annual growth 2006-2015** | **2006** | **2015** | **Average annual growth 2006-2015** |
| South Africa | 6930.7 | 10628.8 | 5.1% | 2032.5 | 3048.1 | 2.5% | 3.4 | 3.4 | 2.4% |
| Zambia | 1427.8 | 2618.2 | 9.7% | 784.5 | 1342.7 | 6.1% | 1.8 | 2.0 | 3.6% |
| Uganda | 1258.0 | 2813.0 | 8.5% | 819.0 | 1125.0 | 3.9% | 1.5 | 2.5 | 4.6% |
| Tanzania | 3423.0 | 5902.8 | 8.2% | 2570.0 | 3787.8 | 5.0% | 1.3 | 1.6 | 3.2% |
| Malawi | 2357.1 | 2776.2 | 2.1% | 1482.4 | 1448.1 | -0.1% | 1.6 | 1.9 | 2.3% |
| Mozambique | 1418.0 | 1500.0 | -1.9% | 1664.0 | 1400.0 | 0.0% | 0.9 | 1.1 | -1.9% |
| Kenya | 3247.3 | 3680.2 | 3.3% | 1888.2 | 2145.5 | 2.6% | 1.7 | 1.7 | 0.7% |
| Zimbabwe | 1484.8 | 742.2 | -2.2% | 1713.0 | 1531.7 | -0.5% | 0.9 | 0.5 | -1.7% |

*Source: Compiled from ReNAPRI (2017)*

Strong production growth must be evaluated within the context of the higher global price cycle, which supported profitability in global agriculture for much of the past decade. Higher prices, combined with a concerted effort to transfer land out of customary tenure to private individuals (Jayne *et al.,* 2016) induced investment into the sector and Africa was one of the most targeted continents for land acquisitions over the past decade (Nolte, Chamberlain & Giger, 2016). Growing investment in the sector has changed the farm structure and supported the emergence of investor farmers operating on farm sizes ranging from 5 to 100 hectares (Jayne *et al.,* 2016). Table 2.3 provides evidence of this changing structure in Zambia. Small farms continue to dominate total cultivated area, but from 2008 to 2014, the share of farms sized between 10 and 20 hectares, as well as 20 to 100 hectares has increased at the expense of those below 5 hectares.

**Table 2.3: Changing farm structure in Zambia**

| **Zambia** | **Number of farms (% of total)** | | | | **% growth in number of farms between initial and latest year** | **% of total operated land on farms between 0-100 ha** | |
|---|---|---|---|---|---|---|---|
| **Size** | **2008** | | **2014** | | | **2008** | **2014** |
| 0 - 5 ha | 984976 | (88.8) | 1142041 | (84.5) | 15.9 | 54.1 | 38.8 |
| 5 - 10 ha | 87719 | (7.9) | 211862 | (9.2) | 141.5 | 19.6 | 25.6 |
| 10 - 20 ha | 29197 | (2.6) | 74959 | (4.0) | 156.7 | 13.3 | 18.1 |
| 20 - 100 ha | 7471 | (0.7) | 22584 | (2.4) | 202.3 | 13 | 17.5 |
| Total | 1109363 | | 1451446 | | 227.2 | 100 | 100 |

*Source: Jayne et al. (2016)*

The rise of medium-scale holdings in most cases reflects increased interest in land by urban-based, politically connected professionals or influential rural households (Jayne *et al.,* 2016). As land sizes increase, opportunities arise for scale benefits, increasing mechanization and further development of support services in the value chain such as input markets, large scale traders and logistics. Provided that the land remains in agricultural production, this combination of factors is indicative of transformation within the African agricultural system and has the potential to deliver accelerated productivity gains.

Another factor that has supported the growing interest in agricultural holdings in Africa, as well as the growth in production volumes, is government expenditure on support programs such as input subsidies. Jayne and Rashid (2013) indicate that ten African governments combined spend roughly US$ 1 billion annually on input subsidy programs, which amounts to 28.6% of public expenditure on agriculture. Within the scope of this study, four countries contribute to this expenditure through various input subsidy programs which, in most instances, include a fertiliser and improved seed package. The programs are as follows:

- The Farm Inputs Support Program (FISP) in Malawi, which targets approximately 50% of producers at a subsidy rate that has increased from 64% in 2006 to 90% by 2011 (Lunduka, Ricker-Gilbert & Fisher, 2013)

- The National Input Voucher System (NAIVS) in Tanzania, which was designed to reach 45% of all smallholders with a 50% subsidy on fertiliser and seed for 0.5ha (Kato & Greeley, 2016), but was replaced by a loan based system in 2014
- The Farmer Input Support Program (FISP) in Zambia, where fertiliser subsidy rates have increased from 50% in 2003 to 79% in 2012 and seed subsidies from 50% to 53% over the same period
- The National Accelerated Agricultural Inputs Access Program (NAAIAP) established in 2007 in Kenya, which is estimated to have reached 5% of Kenyan smallholders by 2010 (Mason, Wineman, Kirimi & Mather, 2017) through input pack vouchers to obtain seed and fertiliser for one acre of maize production

While growth in yields since their implementation in Zambia, Tanzania and Malawi may point to success, yield growth in Kenya has remained limited at less than 1% per annum. Limited yield impacts in Kenya may be attributed to targeting of specific smallholder producers that represent a small share of total production, but literature on the success of these programs also remains divided. Early studies praised Malawi, noting the yield gains achieved and the reduction in imports, while multiple researchers show unequivocally that input subsidy programs have raised national food production (including Mason *et al.*, 2017; Lunduka *et al.,* 2013; Dorward & Chirwa, 2011). Critics have shown that the cost typically outweighs the benefit (Jayne & Rashid, 2013), response rates, particularly of small producers at the bottom end of the income distribution, remain low and poverty rates in Malawi and Zambia did not decline following the introduction of the FISP programs in these countries (Lunduka *et al.*, 2013; Jayne *et al.*, 2011). Furthermore, many of the secondary negative effects, such as the crowding out of alternative public funding on factors such as research and development, as well as detrimental impacts on commercial input purchases, are easy to overlook (Jayne & Rashid, 2013).

Despite the lack of consensus related to the ultimate success of input subsidy programs, recent evidence is more critical of the programs. Nonetheless, even critics such as Jayne and Rashid (2013) note that they are likely to remain in Africa due to the quick and measurable impact on production levels. Mason *et al.* (2017) indicate that efficient targeting at resource poor farmers and the use of vouchers redeemable at commercial input suppliers in Kenya reduced the crowding out of commercial input sectors. It also leads to greater poverty reduction impacts, even if the production impact is smaller than in countries such as Zambia and Malawi. Prioritisation of efficient targeting would therefore improve the benefit of these programs if they continue to be applied.

### 2.3.3 Evolution of maize trade in Eastern and Southern Africa

The infrequent integration and implied isolation of particularly African maize markets in the global context (Baffes *et al.,* 2015; Baquedano & Liefert, 2014; Versailles, 2012; Minot, 2011;) is supported by historic trade patterns. Maize markets in the region remain insulated from world markets by high transportation costs, the preference for white maize and policies that reflect the reluctance to accept maize with GM technology. Consequently, the majority of trade occurs intra-regionally and apart from South Africa, which trades significant quantities of yellow maize for feed consumption in the global market, trade with other countries outside the region has been limited (Figure 2.5). The prevalence of informal trade in the region further suggests that the share of intra-regional trade is most likely higher than that indicated by formal trade statistics[2].

Since 2008, South Africa, Zambia and Uganda have supplied consistent exports into the region, with Tanzanian exports also growing in recent years. Conversely, Kenya, Zimbabwe and Mozambique have remained in deficit. While South Africa is the largest exporter when total global exports (white and yellow maize) are considered, Figure 2.5 suggests that Zambia, as a supplier of predominantly non-GM white maize, has become the largest exporter into the rest of the ESA region in recent years.

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[2] Formal trade refers to official trade statistics, whereas informal trade refers to cross border regional trade, often in small quantities, not captured in the official trade statistics. Total trade statistics quoted in this study includes estimates of informal trade by FEWSNET.

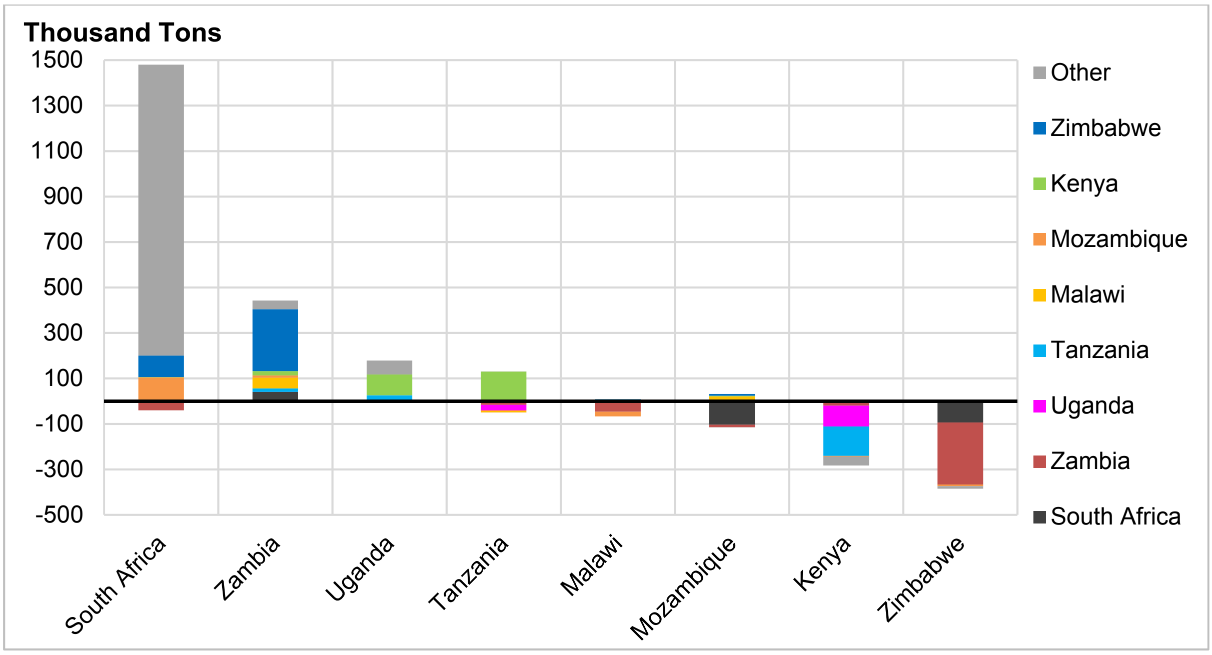

**Figure 2.5: Average net exports between 2012 and 2015, disaggregated by trading partner**[3]
*Source: Compiled from ITC Comtrade (2017) and FEWSNET (2016)*

Figure 2.6 presents typical intra-regional trade-flows, as well as the intensity of production within ESA. As the largest city and major commercial center in East Africa, Nairobi is an important driver in the market and Kenya represents the largest importer in East Africa. Uganda is favourably located to deliver maize into Kenya's main production region in the Rift Valley, while transport rates into Nairobi and Mombasa are often reduced due to a lack of backloads when imported goods are transported inland from the coastal region. Its proximity to Nairobi also allows for surpluses from Northern Tanzania to be transported at competitive rates from Arusha, which remains an important transport hub in Tanzania.

Tanzania itself is a complex market; it covers a large geographical area, characterized by 5 distinct geographic and agro-ecological zones, with self-sufficiency across different regions reflecting a large degree of variation. Whilst surplus markets in the North such as Moshi and Arusha supply into the growing market in Nairobi, the surplus markets in the South remain fairly isolated from large consumption centers such as Dar es Salaam and Dodoma in the central deficit region due to large distances and high transportation costs. Hence cross border trade into Northern Mozambique and Malawi provide additional markets for surplus products (Baffes *et al.,* 2015).

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[3] Trade figures include official trade statistics from ITC database, as well as estimates of informal trade by FEWSNET

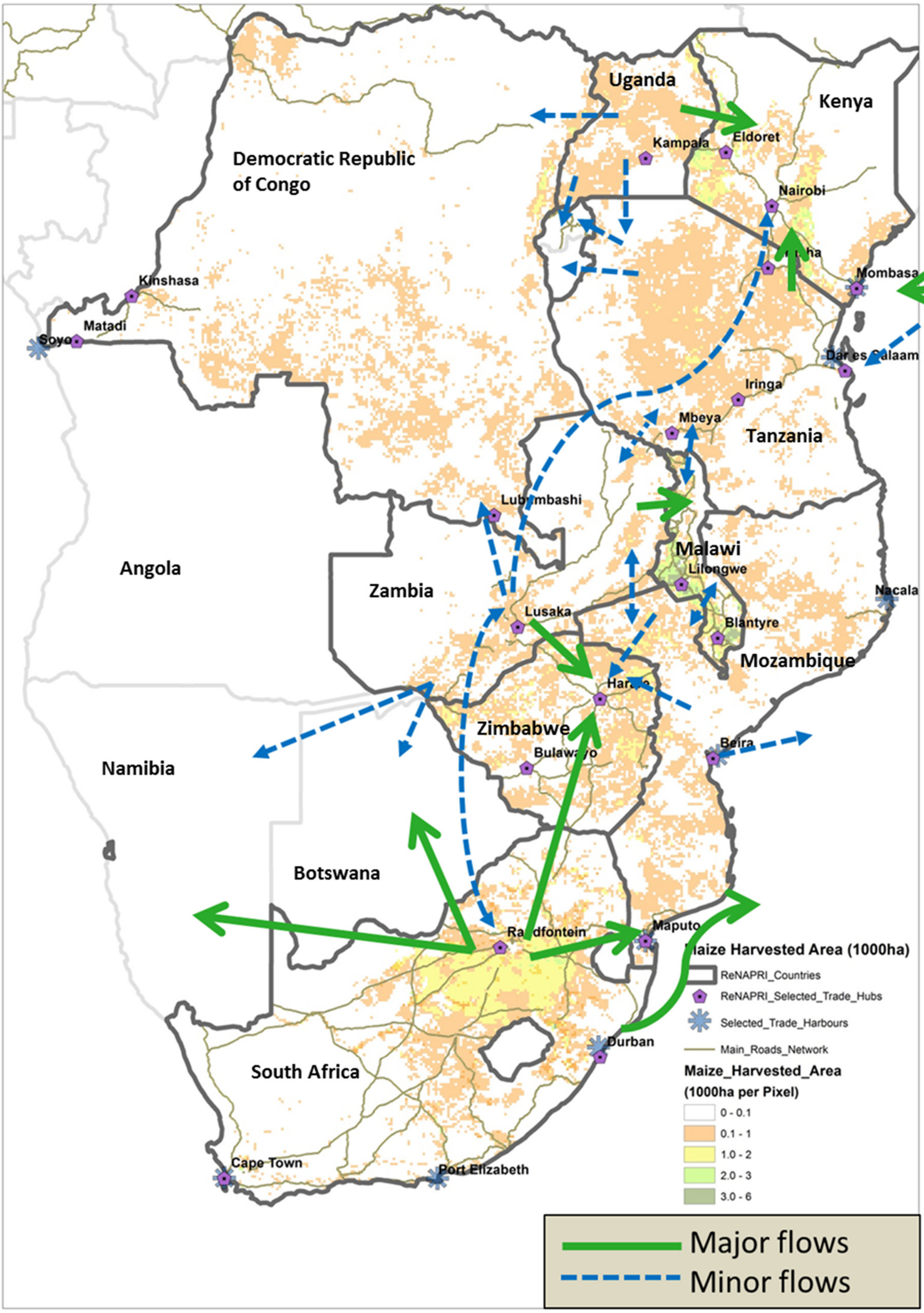

**Figure 2.6: Maize trade-flow in Eastern and Southern Africa – average 2012 to 2015**[4]
*Source: Compiled from ITC (2017), FEWSNET (2016) and GAEZ (2015)*

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[4] Major trade flows imply an annual average of more than 40 000 tons per annum between relevant country pairs over the indicated period and minor trade flows imply an annual average of more than 2 000 tons per annum, but less than 40 000 tons per annum. Trade flows averaging less than 2000 tons per annum are not illustrated on the map.

Malawi represents an intricate market, with poor information related to production volumes and informal cross border trade-flows. Due to its proximity to various surplus regions, imports accrue from a variety of sources, including Northern Mozambique, Tanzania and Zambia, however in different years, exports have also flowed to Mozambique, Tanzania and Zimbabwe.

Mozambique is a very regional market; the Southern region is typically in deficit, relying on imports from South Africa, whereas the Northern regions often produce a surplus. However, high transport costs inhibit maize shipments from the Northern surplus regions to the deficit markets in the South (Tostao & Brorsen, 2005), resulting in a net import position at national level.

Within the Southern African region, Zimbabwe is the largest importer. South Africa represents the traditional source of imports into Zimbabwe, but strong production growth in Zambia over the past decade (Table 2.2) has outpaced consumption growth (Table 2.1), allowing it to capture an increasing share of the regional export market. Competition from Zambian maize into Zimbabwe has been fierce due to more favourable transportation differentials relative to South Africa and the GM free status of Zambian maize.

Changing trade patterns are illustrated in Figure 2.7, which indicates that, between 2003 and 2005, South Africa supplied almost 70% of Zimbabwean imports, compared to only 17% from Zambia. Between 2013 and 2015 however, more than 60% of Zimbabwean imports originated from Zambia, with just over 30% sourced in South Africa. This pattern changes during periods of export controls however, with South Africa typically stepping in to supply Zimbabwe when Zambian exports are controlled. Combined with rising demand for animal feed in South Africa, this increased competition for regional export markets from Zambia has accelerated the shift from white maize production to yellow maize production in South Africa. Consequently, the South African exportable surplus of white maize into the African region has reduced, while increased yellow maize production is consumed in the domestic animal feed market and surpluses exported deep sea into a large global market.

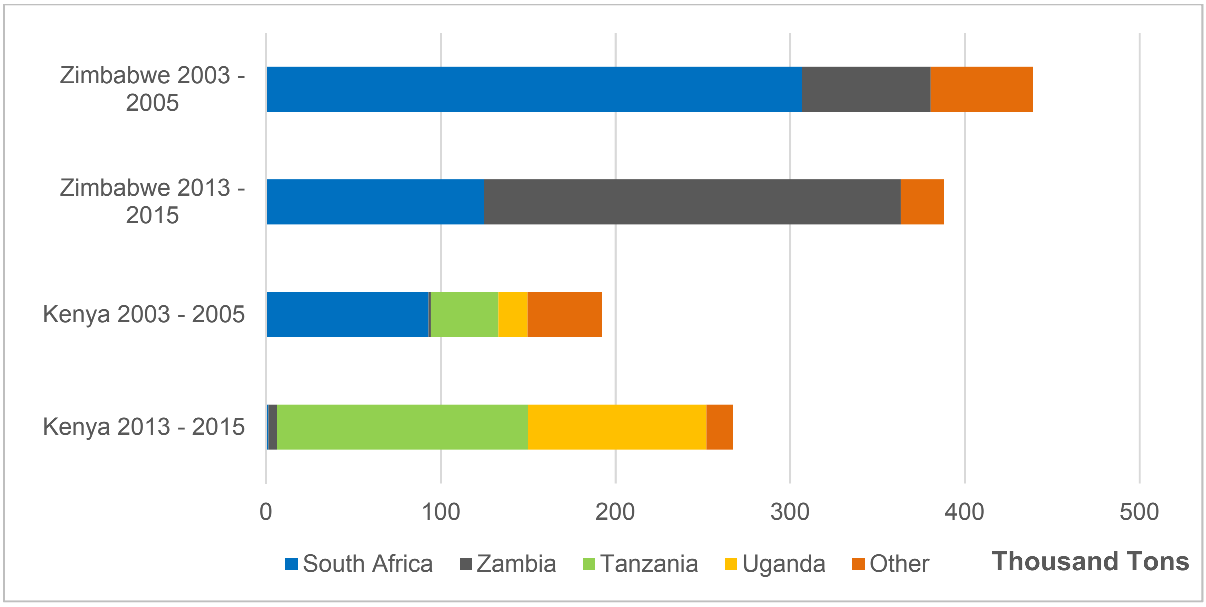

**Figure 2.7: Imports into Zimbabwe and Kenya by country of origin: average 2003-2005 vs. average 2013-2015**
*Source: Compiled from ITC Trademap (2017) and FEWSNET (2016)*

Trade patterns have also shifted in East Africa, illustrated by Kenya as the largest importer (Figure 2.7). Between 2003 and 2005, South Africa supplied almost half of Kenyan imports, with 22% originating from outside the ESA region. Tanzania and Uganda supplied 29% of Kenyan imports between them. Following rapid production growth in Tanzania and Uganda over the past decade (Table 2.2), Kenya has sourced an increasing share of imports from these countries. Between 2013 and 2015, 54% of Kenyan imports originated from Tanzania, with a further 38% sourced in Uganda and merely 6% coming from outside of the ESA region.

The trade patterns evident across the region are also influenced by tariff policies, which are presented by regional trade area and outside of the ESA region in Table 2.4. Member states of the Southern African Development Community (SADC) typically apply zero rated tariffs to other member states, which is also the case amongst members of the Common Market for Eastern and Southern Africa (COMESA) and the East African Community (EAC). Outside of these trade agreements however, countries face significant tariff barriers, with rates ranging from 0% to 50%.

**Table 2.4: Ad-valorem equivalent tariff rates applied to maize imports**

| | SADC[5] | COMESA[6] | EAC[7] | Other |
|---|---|---|---|---|
| **South Africa** | 0% | 0% | 0% | 0% |
| **Zambia** | 0% | 0% | 3% | 15% |
| **Zimbabwe** | 0% | 0% | 0% | 0% |
| **Mozambique** | 0% | 2.5% | 2.5% | 2.5% |
| **Malawi** | 0% | 0% | 0% | 0% |
| **Kenya** | 50% | 0% | 0% | 50% |
| **Uganda** | 50% | 0% | 0% | 50% |
| **Tanzania** | 0% | 50% | 0% | 50% |

*Source: Compiled from Market Access Map (2017)*

The establishment of regional free trade areas such as SADC, COMESA and the EAC has supported the drive towards increased intra-regional trade through tariff reductions. At the same time, Kalaba *et al*. (2016) notes that potential intra-SADC trade has been restricted with an equivocal rise in non-tariff measures. Going forward, increased intra-regional trade will require such measures to be applied in a transparent manner to facilitate compliance and reduce trade restricting impacts.

### 2.4 Maize price relationships in Eastern and Southern Africa

Relative price levels within the ESA region reflect current trade patterns, as well as the substantial cost of transportation within the region. Figure 2.8 illustrates the relative prices, as well as volatility levels in several key markets across ESA. Prices are measured at wholesale level and represent the average price through the 6 months after harvest (harvest average) and the rest of the year (lean average) between 2008 and 2014. As would be expected, prices in deficit regions are consistently higher than those in surplus producing regions, with Maputo, Nairobi and Harare amongst the highest prices in the region. Conversely, consistent surplus producers such as South Africa and Zambia are amongst the lowest in the region.

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[5] Within the modelled region, Malawi, Mozambique, South Africa, Tanzania, Zambia and Zimbabwe are members of SADC

[6] Within the modelled region, Kenya, Malawi, Uganda, Zambia and Zimbabwe are members of COMESA

[7] Within the modelled region, Kenya, Tanzania and Uganda are members of the EAC

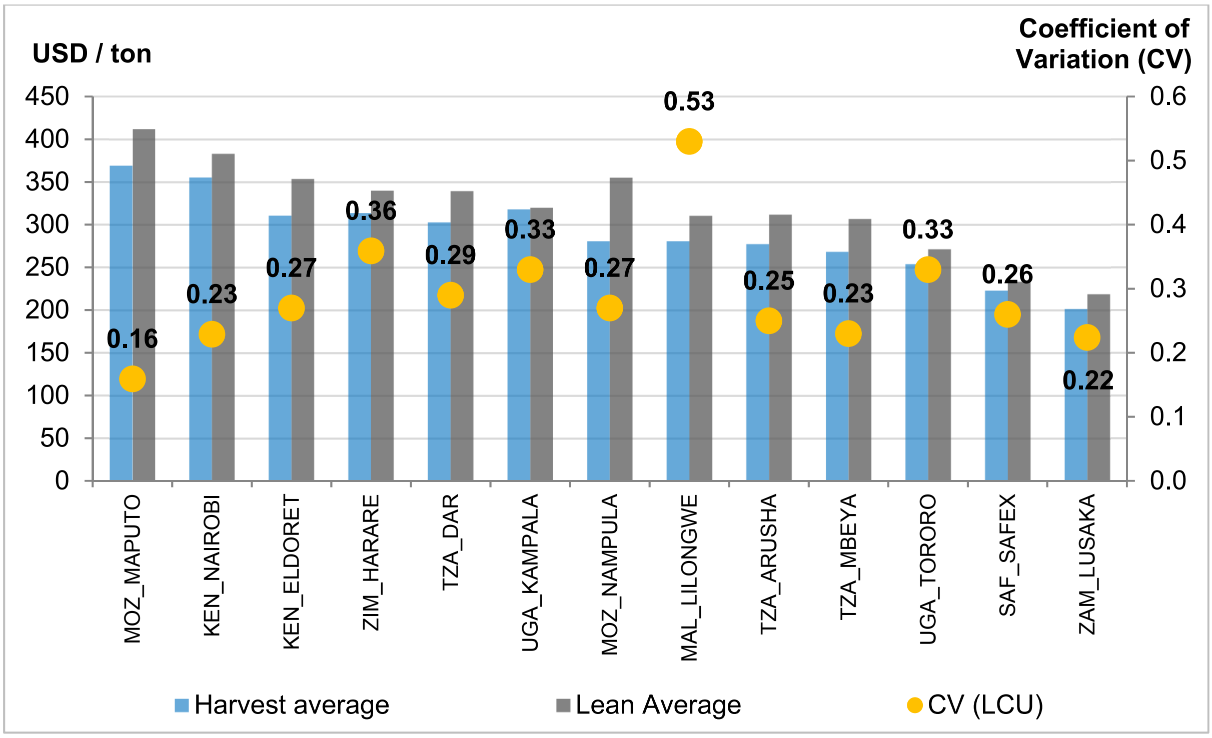

**Figure 2.8: Relative price levels (wholesale) and volatility across Eastern and Southern Africa: 2008 - 2014**
*Source: Compiled from FEWSNET (2015)*

In Nairobi, high prices reflect the cost of transporting maize from surplus regions. In light of changing trade patterns, the expanding market in Nairobi is demonstrating a growing influence on prices in Tanzania and Uganda, where most of its imports now originate from. Baffes *et al.* (2015) indeed notes that, despite domestic factors being a more important determinant, Kenyan markets exert clear influence on Tanzanian prices.

Despite its small size, prices across Malawi show a great deal of variation; markets remain thin, with estimates by the Grain Traders and Processors association indicating that only about 10% of total maize production is traded formally (Edelman & Pauw, 2015). Figure 2.8 indicates that prices in Lilongwe are some of the most volatile in the region, consistent with the findings of Chapoto and Jayne (2009). Whilst mostly operating in an autarkic situation, its proximity to relatively reliable surpluses from Zambia and Northern Mozambique suggests that prices should follow those markets in years of deficit and on routes where informal trade occurs fairly consistently, prices have been shown to transmit efficiently between Mozambique and Malawi (Burke *et al.,* 2014).

In Zimbabwe, the largest importer in Southern Africa, the source of imports often shifts based on trade policy application in Zambia as well as relative price changes in South Africa and Zambia. Consequently, the level of price transmission between these markets is expected to be inconsistent based on changes in trade volumes, but has yet to be quantified. In light of consistent procurement in South Africa, the price in Maputo is derived from the import parity price from South Africa plus a Value Added Tax (VAT) levied on imported maize. During periods of high import volumes, maize prices in Mozambique have been proven to exhibit co-integration with South African prices (Traub *et al.,* 2010).

Amidst climate related fluctuations in production, the differences in harvested and lean period price levels would suggest that stocks have a significant influence on volatility. In many ESA countries, stock holding is limited by infrastructural constraints and often the majority of stocks are held as strategic food reserves by government. The establishment of such food reserve programs was a resolution within the Maputo declaration on agriculture and food security. Institutes mandated to manage such reserves include the National Cereals and Produce Board (NCPB) in Kenya, the National Food Reserve Agency (NFRA) in Malawi and Tanzania, the Food Reserve Agency (FRA) in Zambia and the Grain Marketing Board (GMB) in Zimbabwe. Such institutes have represented active agents in the market, buying stocks through harvest time and releasing again as required, whilst often being active and even controlling trade flow. As such, they have been shown to exert significant influence on markets both in terms of volatility and price levels (Mason & Myers 2013; Jayne *et al.,* 2008). While the maintenance of such reserves is justifiable, design in line with the specific objectives of the policy, as well as transparent implementation and pricing is key to achieving success and limiting market distorting impacts.

Africa has been the subject of numerous studies related to heightened volatility and increased prices following the global food crisis in 2007/08 and consistently, researchers have pointed to domestic rather than global factors as the source of domestic market volatility (Baffes *et al*., 2015; Baquedano & Liefert, 2014; Minot, 2011). While a number of factors within these domestic markets can influence price volatility, including climate related fluctuations in production volumes, the potential of increased intra-regional trade as an inexpensive means of reducing domestic price volatility has been acknowledged (Morrison, 2016; World Bank, 2012; Dorosh, Dradri & Haggblade, 2009). At the same time, the prevalence of intra-regional trade suggests that the effects of supply shocks or unpredictable policy interventions in a particular country can spread beyond its borders. Quantification of the speed and magnitude of price transmission between markets is necessary to fully understand price formation and regional influence between markets. The impact of trade and policy on such price transmission patterns must also be understood and can be illustrated through an anlysis of Southern African markets.

### 2.4.1 Price transmission and co-integration in Southern African maize markets

Early analysis of price relationships in Southern Africa focussed on the extent to which international reference prices are transmitted into domestic markets in the region. Conforti (2004) noted that relative to other developing markets in Asia and South America, transmission from world to domestic prices in Africa is much poorer. This was later confirmed by Minot (2011) who evaluated 62 markets in Africa, finding evidence of long run relationships to world prices in only 13. Of all maize markets tested only 10% of domestic markets were found to be co-integrated to world prices.

A contributing factor to the lack of long run co-integrating relationships between domestic and world prices is the preference for non-GM white maize, which limits procurement opportunities in the world market. Instead, the prevalence of intra-regional trade suggests that different regional markets may well exhibit co-integrating behaviour. More recent evaluations of price transmission have therefore focussed on the extent to which South African prices, as the traditional surplus producer, are transmitted into the rest of the region.

Whilst noting that price transmission may still take place in the absence of trade based on the flow of information between markets and trade in substitute products, various authors have linked trade-flow to price transmission analysis in the region. Trade volumes have been applied as a threshold variable to allow for multiple thresholds and price transmission regimes between South Africa and Mozambique (Traub et al., 2010), as well as South Africa and Zambia (Myers & Jayne, 2012). Essentially the efficiency of price transmission between different markets is allowed to vary depending on the magnitude of trade-flow between markets. Traub *et al.* (2010) confirmed co-integration between prices in South Africa and Mozambique under a high import regime, but no evidence of a long run price relationship in a low import regime. Conversely, Myers and Jayne (2012) found evidence of price transmission from South Africa to Zambia during periods of low imports, but no transmission during periods of high imports (typically when government is heavily involved in importation). Therefore, they concluded that government imports sold at subsidised prices effectively break the price-link with the South African market.

The focus on the impact of policies on price transmission patterns was extended by Burke and Myers (2014), who evaluated price transmission patterns between markets where informal trade dominates. This provides an environment of largely unregulated trade-flow and long-run price equilibrium was found to be consistent with competitive trade patterns and price transmission rapid. The combined findings of Traub *et al.* (2010), Myers and Jayne (2012), as well as Burke and Myers (2014) suggest that government involvement in markets does have a significant impact on efficiency and that trade volumes are an important consideration in evaluating price transmission between markets. Given that the studies consider different markets, multiple other factors can also contribute to the findings.

The price transmission analysis conducted in this section considers a wider geographical scope and more recent time-period compared to previous price transmission studies in ESA. In doing so, it aims to broaden the knowledge base on differences in long run price equilibrium under different regimes defined firstly by trade volumes across a number of trading market pairs and secondly by trade policy. Particularly in defining regimes based on export control policy implementation in Zambia, it considers the impact of policies on market efficiency more explicitly than previous authors such as Myers and Jayne (2012).

### 2.4.2 Data and methodology for analysis of trade defined regimes

The evolution of co-integration and price transmission analysis has provided an increasingly popular tool to evaluate the extent of interaction between spatially separated markets. Derived from spatial equilibrium theory, the concept is underpinned by the Law of One Price (LOP) and rests on the theory that, under conditions of spatial arbitrage, price differences between markets cannot exceed the transaction costs associated with trade between such markets. Thus, despite deviations in short run price movements, long run prices will equalise across regions after accounting for transportation costs. In practice, researchers have recognised that difficulties in measuring total transaction costs result in empirical tests rarely supporting the LOP fully and instead have focused on co-integration and price transmission analysis.

The essence of such analysis is to determine whether prices share a long run relationship, and if they do, to estimate this relationship, along with the dynamic process which leads the prices to return to this long run equilibrium following an external shock. Two principal approaches have been adopted: 1) The 2-step residual based test for co-integration first proposed by Engle and Granger (1987), or 2) the system based reduced rank regression proposed by Johansen (1991). These approaches have been refined in recent years, resulting in multiple sophisticated methodologies to evaluate price transmission.

Transaction costs are not always explicitly included, but its influence is acknowledged by threshold methodologies that estimate “inactive bands” associated with unobservable transaction costs, where the extent of co-integration differs within and outside of the band (Balke & Fomby, 1997; Mainardi, 2001; Goodwin & Piggott, 2001; Goodwin & Harper, 2000). Alternative methodologies related to the parity bounds model include transportation costs explicitly, estimating the probability of spatial price regimes that are consistent with the equilibrium notion of fully exploiting arbitrage opportunities (Negassa & Myers, 2007; Barrett & Li, 2002; Sexton, Cling & Carmin, 1991). A recent specification of a threshold autoregressive (TAR) model by Myers and Jayne (2012) allows for multiple regimes, separated by the magnitude of trade volumes and has been effective in accounting for non-linearity of price transmission.

Meyers and Jayne (2012) note that a simple, 2-regime model can be described as in equation 1 below, where $X_t$ is the explanatory variables and θ the associated parameters, $q_{1t}$ represents imports into the country of interest and $\delta_1$ the critical threshold import level above which the price transmission process changes.

$$\Delta p_t = f\left(X_{t,}\theta_1\right) + \epsilon_t \qquad q_{1t} \leq \delta_1 \tag{1a}$$

$$\Delta p_t = f\left(X_{t,}\theta_2\right) + \epsilon_t \qquad q_{1t} > \delta_1 \tag{1b}$$

Threshold estimation is computed through a grid search procedure conditional on maintaining a minimum number of parameters in each regime and is detailed in Hansen (2000). Estimation is simple, but testing to determine the number of threshold parameters is complicated by the problem of under-identified nuisance parameters under the null of no thresholds. Hansen (1996) therefore detailed an alternative bootstrap procedure to test the null hypothesis of no thresholds against the alternative of a single threshold. Gonzalo and Piterakis (2002) suggest the use of a Bayesian Information Criterion (BIC)-like criterion function to account for multiple thresholds in a single set of prices, but given that the analysis presented in this section is limited to a single threshold due to the short data series, the computationally simpler method of Hansen (1996) is sufficient for threshold identification.

Following the methodology of Myers and Jayne (2012), regime specific tests need to be conducted in order to quantify the long run price relationships. The single equation error correction model proposed by Myers and Jayne (2012) however is only straightforward under the assumption that prices are co-integrated in every regime. In order to allow for situations where relevant prices are not co-integrated under certain regimes, they propose preliminary, regime-specific unit root and co-integration tests, with the single equation error correction model applied to quantify parameters in instances where long run co-integration is confirmed. Recognising that this approach is biased towards finding no long-run cointegrating relationship between series, they carry out regime specific estimates of the long run price transmission and speed of adjustment parameters for all series under the assumption of co-integration as well, thus providing maximum opportunity for identification of price transmission. The analysis provided in this section follow this methodology closely.

The different approaches that could be applied to test for regime specific co-integration and price transmission have been refined rapidly in recent years, but most of them, including the single equation error correction model applied by Myers and Jayne (2012) remain based on the assumption that the underlying variables are integrated of order one, which must be established through pre-testing. Noting the possible uncertainty associated with such pre-testing, Pesaran, Shin and Smith (2001) proposed an alternative methodology, which is applicable regardless of whether the underlying series are purely I(1), purely I(0) or mutually co-integrated. Combined with the autoregressive distributed lag model (ARDL), they developed a bounds test, which was found to be consistent on both I(1), I(0) and a mix of I(1) and I(0) series. This methodology has the advantage of still being able to employ an error correction estimation process, maintaining the ability to draw inference on long term relationships and short run dynamics, but also yield inference on the results regardless of the series underlying order of integration. These attributes have popularised it as an alternative methodology for price transmission analysis.

The theoretical specification of the ARDL model can be presented as follows:

$$Y_t = c_0 + c_{1t} + \sum_{i=1}^{p} \emptyset_i Y_{t-i} + \sum_{i=0}^{q} \beta_i x_{t-i} + \mu_t \quad (2)$$

The variables $x_t$ and $Y_t$ are allowed to be I(1), I(0) or co-integrated. Reparameterization yields the error correction specification below:

$$\Delta y_t = c_0 + c_{1t} - \alpha\left(y_{t-1} - \theta_{x_t}\right) + \sum_{i=1}^{p-1} \omega_{yi} \Delta y_{t-i} + \sum_{i=0}^{q-1} \omega'_{xi} \Delta x_{t-i} + \mu_t \quad (3)$$

$\alpha = 1 - \sum_{j=1}^{p} \emptyset_i$ represents the speed of adjustment and the long run coefficient $\theta = \frac{\sum_{j=0}^{q} \beta_j}{\alpha}$.

The coefficient on the error correction term $\alpha$ gives an indication of the length of time required for a shock that causes dis-equilibrium to dissipate through the system. A negative coefficient confirms convergence back to equilibrium conditions following an external shock, while the magnitude of the coefficient is indicative of the time required to return to equilibrium and is used to calculate the half-life.

Preliminary tests conducted on the complete datasets, as well as the regime-specific datasets used in this analysis to evaluate the time-series properties include the Augmented Dickey Fuller (ADF), Phillips Peron (PP) and Kwiatkowski, Phillips, Schmidt, and Shin (KPSS). The null hypothesis of both the ADF and PP test assume non-stationarity, whereas the KPSS test is based on the null hypothesis of stationarity. The differences in design render the tests good complements and when the ADF and PP tests fail to reject the null hypothesis whilst the KPSS rejects it, strong evidence of the presence of a unit root can be assured. In many instances however, the results from the ADF, PP and KPSS tests did not support each other, yielding somewhat inconclusive evidence related to the presence of a unit root. Results of the tests performed in levels and first difference form are provided in Appendix 1. Given the nature of the results, the use of an ARDL specification, combined with the bounds test proposed by Pesaran *et al.* (2001) is proposed for the evaluation of the entire series, as well as the regime specific analysis. This enables inference to be drawn regardless of the uncertainty associated with the unit root properties of the underlying data series.

The empirical analysis is focused in Southern Africa and considers monthly data of white maize wholesale prices form different cities in Malawi, Mozambique, Zambia, Zimbabwe and South Africa, presented in the US dollars. The time-frame of the analysis is defined by availability in the data set and covers January 2005 to October 2014. Summary statistics for the data is presented in Table 2.5.

**Table 2.5: Summary statistics of the data used in the analysis (January 2005 – October 2014)**

| | Unit | Obs. | Mean | Min | Max | Std. dev. | Source |
|---|---|---|---|---|---|---|---|
| **South Africa: SAFEX Randfontein** | USD/ton | 118 | 212.9 | 86.8 | 342.3 | 58.9 | SAFEX |
| **Zambia: Lusaka** | USD/ton | 118 | 254.5 | 127.6 | 378.8 | 50.7 | FEWSNET |
| **Zimbabwe: Harare** | USD/ton | 118 | 277.1 | 20.0 | 860.0 | 138.3 | FEWSNET |
| **Mozambique: Maputo** | USD/ton | 118 | 380.8 | 190.5 | 533.0 | 89.4 | FEWSNET |
| **Mozambique: Tete** | USD/ton | 118 | 282.6 | 121.5 | 642.9 | 110.0 | FEWSNET |
| **Malawi: Lilongwe** | USD/ton | 118 | 263.1 | 133.0 | 478.4 | 85.7 | FEWSNET |
| **RSA exports to Zambia** | Tons | 118 | 1 911.8 | 2.3 | 41 560.3 | 6 341.3 | ITC Trademap |
| **RSA exports to Zimbabwe** | Tons | 118 | 21 710.6 | 0.0 | 124 682.6 | 28 190.3 | ITC Trademap |
| **RSA exports to Mozambique** | Tons | 118 | 7 492.0 | 27.6 | 58 221.0 | 7 710.9 | ITC Trademap |
| **Zambia exports to Zimbabwe** | Tons | 118 | 10 154.4 | 0.0 | 59 364.1 | 14 065.5 | ITC Trademap |
| **Zambia exports to Malawi** | Tons | 118 | 545.6 | 0.0 | 6 840.0 | 1 268.6 | ITC Trademap |
| **Malawi imports from Mozambique** | Tons | 118 | 1 192.8 | 0.0 | 18 240.0 | 2 360.6 | ITC Trademap |

### 2.4.3 Results for analysis of trade defined regimes

As a starting point for the empirical analysis, an ARDL model was used to estimate the extent of co-integration between the relevant price pairs over the entire data series. Results of the bounds test of Pesaran *et al.* (2001) are presented in Table 2.6, which supports long-run co-integration between South Africa and Zambia, South Africa and Mozambique (Maputo) as well as Mozambique (Tete) and Malawi.

**Table 2.6: Results of the ARDL model estimation over the entire series**

| Dependent | Independent | F-Statistic | F-Stat bound (10%) | | F-Statistic decision | Implication |
|---|---|---|---|---|---|---|
| | | | Lower | Upper | | |
| Zambia: Lusaka | South Africa: Randfontein | 5.5 | 4.04 | 4.78 | Reject | Co-integrated |
| Zimbabwe: Harare | Zambia: Lusaka | 3.54 | 4.04 | 4.78 | Accept | Not-cointegrated |
| Zimbabwe: Harare | South Africa: Randfontein | 3.73 | 4.04 | 4.78 | Accept | Not-cointegrated |
| Mozambique: Maputo | South Africa: Randfontein | 6.30 | 4.04 | 4.78 | Reject | Co-integrated |
| Malawi: Lilongwe | Mozambique: Tete | 35.13 | 4.04 | 4.78 | Reject | Co-integrated |
| Malawi: Lilongwe | Zambia: Lusaka | 4.03 | 4.04 | 4.78 | Accept | Not-cointegrated |

Given that the presence of multiple price transmission regimes as trade varies over time could result in a different conclusion, Table 2.7 presents the results of the threshold estimation within the different price pairs. It also includes the number of observation above and below the threshold (T), the BIC criterion which was minimized for selection of the appropriate threshold level and the p-value of the Hansen test for the null hypothesis of no threshold against the alternative of a single threshold. At a 10% level of significance, the existence of different regimes was confirmed in the South Africa-Zambia, Zambia-Zimbabwe and Mozambique-Malawi price pairs. Given that thresholds estimated for the South Africa-Mozambique price pair is significant at 11%, which is very close to conventional levels, it is also retained for further estimations. Within the Zambia-Malawi price pair and the South Africa-Zimbabwe price pair, the null hypothesis of no threshold was not rejected, hence the threshold was found to be insignificant.

**Table 2.7: Price transmission threshold estimation results**

| Dependent variable | Independent variable | Threshold variable | Threshold estimate | T (Below) | T (Above) | BIC Value | Hansen P-value |
|---|---|---|---|---|---|---|---|
| Zambia: Lusaka | South Africa: Randfontein | South Africa exports | 690.3 | 103 | 16 | -716.6 | 0.09 |
| Zimbabwe: Harare | Zambia: Lusaka | Zambia exports | 221.8 | 26 | 92 | -711.6 | 0.07 |
| Zimbabwe: Harare | South Africa: Randfontein | South Africa exports | 5897.8 | 54 | 64 | -342.1 | 0.80 |
| Mozambique: Maputo | South Africa: Randfontein | South Africa exports | 10381.5 | 97 | 21 | -731.8 | 0.11 |
| Malawi: Lilongwe | Mozambique: Tete | Malawi Imports | 31.0 | 31 | 87 | -610.5 | 0.09 |
| Malawi: Lilongwe | Zambia: Lusaka | Zambia exports | 430.8 | 89 | 29 | -615.2 | 0.28 |

Having applied the thresholds presented in Table 2.7, repetition of the ARDL bounds test procedure within the specified regimes yields the results presented in Table 2.8. To evaluate the impact of allowing for non-linearity, the price pairs where the threshold was found to be insignificant are retained in the analysis. Interestingly, accounting for different regimes supports long run co-integration between South African and Zambian prices at low trade levels, but not at high trade levels. While this seems counter intuitive, it is consistent with the findings of Myers and Jayne (2012), which was based on earlier data ending in 2009. The typical involvement of the FRA in high volume trade was presented as a possible reason for the finding and the consistency of this analysis suggests that this has not changed now that Zambia has become a surplus producer.

**Table 2.8: Co-integration tests in different regimes**

| Dependent | Independent | Threshold | Regime 1: Below threshold | | Regime 2: Above threshold | |
|---|---|---|---|---|---|---|
| | | | **F-Stat** | **Decision** | **F-Stat** | **Decision** |
| Zambia: Lusaka | South Africa: Randfontein | 690.3 | 10.62 | Co-integrated | 1.35 | Not Co-integrated |
| Zimbabwe: Harare | Zambia: Lusaka | 221.8 | 9.31 | Co-integrated | 12.31 | Co-integrated |
| Zimbabwe: Harare | South Africa: Randfontein | 5897.8 | 2.35 | Not Co-integrated | 8.58 | Co-integrated |
| Mozambique: Maputo | South Africa: Randfontein | 10381.5 | 8.04 | Co-integrated | 10.56 | Co-integrated |
| Malawi: Lilongwe | Mozambique: Tete | 31.0 | 112.64 | Co-integrated | 43.88 | Co-integrated |
| Malawi: Lilongwe | Zambia: Lusaka | 430.8 | 2.82 | Not Co-integrated | 5.08 | Co-integrated |

Other price pairs were more consistent with prior expectation and despite the Hansen test finding the threshold in the South Africa-Zimbabwe and Zambia-Malawi price pairs to be insignificant, evidence of cointegration is found above the estimated threshold in both series. It should be noted however that the small sample size above the threshold in the South Africa-Zambia, South Africa-Mozambique and Zambia-Malawi price pairs is problematic for robust conclusions related to the parameters. Long run co-integration was also found between Zambia and Zimbabwe in both regimes when they are accounted for, as opposed to no co-integration being identified over the entire series.

Regime-specific, as well as full sample parameters of the ARDL estimated in error correction form is presented in Table 2.9. While co-integration was not confirmed in all of the price pairs presented, estimation of the parameters for all series is in line with Myers and Jayne (2012) noting the possible bias in concluding no long-run relationship and therefore maximizes the possibility of detecting price transmission between markets.

**Table 2.9: Full sample and regime specific parameter estimates**

| Dependent variable | Independent variable | Regime | Long run coefficient (p-value) | Adjustment rate (p-value) | Half-life, months | Adj $R^2$ |
|---|---|---|---|---|---|---|
| Zambia (Lusaka) | South Africa (Randfontein) | Full sample | *0.31*<br>*(0.27)* | _-0.15**_<br>*(0.002)* | *4.3* | *0.07* |
| | | Regime 1: Below threshold | 0.24<br>(0.21) | -0.33**<br>(0.00) | *1.7* | 0.17 |
| | | Regime 2: Above threshold | 2.68<br>(0.44) | -0.28<br>(0.20) | *2.1* | 0.50 |
| Malawi (Lilongwe) | Mozambique (Tete) | Full sample | 0.74**<br>(0.00) | -0.47**<br>(0.00) | *1.1* | 0.38 |
| | | Regime 1: Below threshold | 0.79**<br>(0.00) | -0.92**<br>(0.00) | *0.3* | 0.90 |
| | | Regime 2: Above threshold | 0.73**<br>(0.00) | -0.64**<br>(0.00) | *0.7* | 0.51 |
| Zimbabwe (Harare) | Zambia (Lusaka) | Full sample | 0.66<br>(0.49) | -0.18**<br>(0.01) | *3.5* | 0.17 |
| | | Regime 1: Below threshold | 2.74**<br>(0.001) | -0.99**<br>(0.001) | *0.2* | 0.40 |
| | | Regime 2: Above threshold | 0.46<br>(0.33) | -0.45**<br>(0.0000) | *1.2* | 0.20 |
| Mozambique (Maputo) | South Africa | Full sample | 0.26<br>(0.50) | -0.17**<br>(0.00) | *3.7* | 0.1 |
| | | Regime 1: Below threshold | 0.32<br>(0.34) | -0.30**<br>(0.00) | *1.9* | 0.13 |
| | | Regime 2: Above threshold | -0.04<br>(0.89) | -0.95**<br>(0.21) | *0.2* | 0.54 |
| Zimbabwe (Harare) | South Africa | Full sample | 0.81<br>(0.41) | -0.15**<br>(0.01) | *4.3* | 0.17 |
| | | Regime 1: Below threshold | 0.33<br>(0.76) | -0.07**<br>(0.05) | *9.6* | 0.12 |
| | | Regime 2: Above threshold | 1.07<br>(0.13) | -0.43**<br>(0.00) | *1.23* | 0.2 |
| Malawi (Lilongwe) | Zambia (Lusaka) | Full sample | 0.34<br>(0.58) | -0.15**<br>(0.01) | *4.3* | 0.05 |
| | | Regime 1: Below threshold | 0.76<br>(0.35) | -0.14**<br>(0.05) | *4.6* | 0.13 |
| | | Regime 2: Above threshold | 0.19<br>(0.74) | -0.58**<br>(0.01) | *0.8* | 0.42 |

_Asterisks denote the level of significance (*10%, **5%)_

From the analysis presented, all series where the threshold was found to be significant reflected evidence of co-integration above the threshold except for South Africa and Zambia. As was highlighted by Myers and Jayne (2012), this could be the result of typical FRA activity in the market when high volumes are traded. On a more technical front, it could also be the result of a very small sample of only 16 observations above the threshold and should therefore be interpreted with caution. In the two series where the threshold was not found to be significant at conventional levels, the bounds test is indicative of a co-integrating relationship above the threshold and while the long run price transmission parameters were not found to be significant, the error correction model points to a faster adjustment towards equilibrium above the threshold than below.

Despite evidence of several co-integrating relationships, the estimates only yielded significant long run price transmission coefficients in a few price pairs – notably for Malawi and Mozambique (Tete) over the full sample and both regimes, as well as the below threshold regime in the Zambia-Zimbabwe price pair. By contrast, the short run adjustment parameter was found to be significant in all the full series and across all regimes, with the lone exception of the above threshold regime in the South Africa-Zambia price pair. The challenge of the small sample size in that regime has been noted. The adjusted R-squared parameters presented indicate that the goodness of fit remains low in most series, which is consistent with the notion of prices being transmitted between markets in the region, but domestic supply and demand factors exerting a greater influence than neighbouring markets on domestic price levels.

In half of the price pairs, the adjustment towards equilibrium was found to be significantly faster at high trade regimes relative to low trade regimes, notably this includes the pairs where the thresholds were not found to be significant. In both the South Africa-Zambia and Zambia-Zimbabwe price pairs, the adjustment towards equilibrium was faster in the low trade regime relative to the high trade regime, which is contrary to prior expectation. Half-life adjustment periods range from 0.2 months on shorter transportation routes such as South Africa-Mozambique and Zambia-Zimbabwe to 9.6 months in a low trade regime from South Africa to Zimbabwe.

Overall, the challenges to accurate parameter estimation are well noted, particularly given the small sample size evident in many of the regimes. Importantly however, the analysis provides clear evidence that trade routes are typically subject to different price transmission regimes as trade levels fluctuate over time. While several authors have noted that trade is not required for price transmission between markets to occur, trade volumes are shown to have a significant impact on both long run price transmission between markets and the short run adjustment towards this equilibrium relationship.

Both Burke and Myers (2014) and Myers and Jayne (2012) allude to the impact of policy on price transmission between markets in the region, but neither specifically account for policies in the estimations. This lack of explicit policy inclusion has been a traditional weakness of price transmission analysis. While it is proposed that the price transmission parameters summarise the overall effects of different factors that affect prices in different markets, it fails to separate the roles of different individual factors. Policies such as intervention prices, export subsidies, export controls and non-tariff barriers can have a significant impact on price transmission. This is particularly relevant to Zambia, which has been prone to imposing discretionary export controls.

### 2.4.4 Data and methodology for analysis of policy defined regimes

Given that some of the results from the trade refined regime analysis remain counter intuitive, an alternative analysis would be more explicit policy consideration. Accounting specifically for discretionary application of export controls, this section evaluates monthly price data from Zambia, South Africa and Zimbabwe under exogenously defined, policy related regimes. Its favourable transport differential and non-GM status has made Zambia the preferred supplier to Zimbabwe in recent years, but South Africa has stepped in when a) its prices were more favourable or b) Zambian exports were controlled (Figure 1.2). These three markets therefore provide an ideal platform to test the hypothesis that a) Zimbabwean prices are derived from Zambian prices during periods of open trade, but from South African prices when Zambian exports are restricted and b) that price transmission is more rapid and efficient under an open trade regime.

The analysis applies the same ARDL and bounds test procedure proposed by Pesaran *et al.* (2001) and detailed in Section 2.4.2. The choice of methodology is based on the often-conflicting results found in pre-tests related to the time series properties of the data. The results of the pre-tests, conducted using the ADF, PP and KPSS methodologies due to the noted differences in design are presented in Appendix 2.

The analysis is based on secondary data of nominal white maize wholesale prices of monthly frequency from 2005 to 2016. To allow testing for differences between open trade and trade controlled regimes, the series is separated exogenously based on periods of trade restrictions as imposed by the Zambian government and periods of open trade. The sources of the relevant data, as well as the summary statistics of the different regimes is presented in Table 2.10.

**Table 2.10: Summary statistics, source and time period of price data used in the analysis**

| Market | Regime | Mean | Min | Max | Source | Observations |
|---|---|---|---|---|---|---|
| Zambia: Lusaka | Open | 236.56 | 150.00 | 350.00 | FAO GIEWS | 90 |
| Zambia: Lusaka | Closed | 274.42 | 160.00 | 420.00 | FAO GIEWS | 52 |
| South Africa: Randfontein | Open | 225.89 | 90.00 | 340.00 | SAFEX | 90 |
| South Africa: Randfontein | Closed | 208.65 | 90.00 | 320.00 | SAFEX | 52 |
| Zimbabwe: Harare | Open | 236.47 | 20.00 | 390.00 | FEWSNET & Commodity Insight Africa | 90 |
| Zimbabwe: Harare | Closed | 295.26 | 60.00 | 860.00 | FEWSNET & Commodity Insight Africa | 52 |

### 2.4.5 Results for analysis of policy defined regimes

The ARDL is estimated in error correction (ECM) form, using Stata software. Under each regime, the ARDL model is used to estimate the extent of price transmission between Zambia and Zimbabwe, as well as South Africa and Zimbabwe. The results from the open trade regime (Regime 1) are presented first in Table 2.11, which shows the number of lagged dependent variables included, the short run adjustment coefficient and the half-life correction period. The trend specification was used only when significant.

**Table 2.11: Results of the ARDL model estimation in the open trade regime**

| Dependent | Independent | Nr lagged dependant | $\theta$ | SR Adj | Half-life | Trend |
|---|---|---|---|---|---|---|
| Zimbabwe: Harare | Zambia: Lusaka | 0 | 1.03** | -0.25** | 2.77 | 0.79** |
| Zimbabwe: Harare | South Africa: Randfontein | 1 | 0.12 | -0.16** | 4.33 | 0.45* |

*Asterisks denote the level of significance (*10%, **5%)*

In both instances, the negative coefficient on the short run adjustment parameter is indicative of an equilibrium correcting process. The long run parameter ($\theta$) is however not significant when the South African price is used as independent variable.

Application of the bounds test, the results of which are presented in Table 2.12 and Table 2.13, confirm a long run relationship between Zimbabwean and Zambian prices under this regime, as both the t-test and the F-test proposed by Pesaran *et al.* (2001) reject the null hypothesis of no relationship. Conversely, when the South African price is used as independent variable, both the F-test and the t-test accept the null hypothesis of no relationship.

**Table 2.12: Results of the Pesaran Shin Smith Bounds F test under an open trade regime**

| Dependent | Independent | F-Statistic | F-Stat bound | | F-Statistic decision | Implication |
|---|---|---|---|---|---|---|
| | | | Lower | Upper | | |
| Zimbabwe: Harare | Zambia: Lusaka | 6.77 | 5.59 | 6.26 | Reject | Co-integration |
| Zimbabwe: Harare | South Africa: Randfontein | 4.17 | 5.59 | 6.26 | Accept | No co-integration |

**Table 2.13: Results of the Pesaran Shin Smith Bounds T test under an open trade regime**

| Dependent | Independent | T-Statistic | T-Stat bound | | T-Statistic decision | Implication |
|---|---|---|---|---|---|---|
| | | | Lower | Upper | | |
| Zimbabwe: Harare | Zambia: Lusaka | -3.67 | -3.13 | -3.40 | Reject | Co-integration |
| Zimbabwe: Harare | South Africa: Randfontein | -2.77 | -3.13 | -3.40 | Accept | No co-integration |

The results obtained under the open trade scenario are in line with prior expectation and confirm a long run co-integrating relationship between prices in Zimbabwe and Zambia. The half-life correction period suggests that it takes 2.77 months for half of the disequilibrium caused by an exogenous shock to decimate through the system. Repeating the same tests on the alternative regime of trade controls (Regime 2) yields the results presented in Table 2.14, Table 2.15 and Table 2.16. In this instance, the model is specified without a trend owing to its insignificance at conventional levels.

Under the restricted trade regime, the long-run co-integration coefficient is no longer significant when Zambian prices are used as independent variable to estimate Zimbabwean prices. The short run adjustment coefficient remains significant, but the adjustment process is marginally slower than that of the open trade regime. This is reflected in a half-life of 3 months as opposed to 2.77 months for the open trade regime. The long-run co-integration coefficient when Zimbabwean prices are estimated as a function of South African prices is also not significant at conventional levels, though it is worth noting that it would be significant at 15%. The rate of adjustment presented by the short run adjustment coefficient is however faster with a calculated half-life of 2 months. In both instances, the short run adjustment coefficient remains indicative on a convergence towards equilibrium following a shock.

**Table 2.14: Results of the ARDL model estimation in the restricted trade regime**

| Dependent | Independent | Nr lagged dependant | θ | SR Adj | Half-life | Trend |
|---|---|---|---|---|---|---|
| Zimbabwe: Harare | Zambia: Lusaka | 2 | 2.17 | -0.23** | 3.01 | N / A |
| Zimbabwe: Harare | South Africa: Randfontein | 0 | 1.35 | -0.34** | 2.04 | N/A |

*Asterisks denote the level of significance (*10%, **5%)*

The results from the bounds tests presented by Pesaran *et al.* (2001) are presented in Table 2.15 and Table 2.16. These results suggest that contrary to the open trade regime, Zimbabwe and Zambian prices are no longer co-integrated under the controlled trade regime. Instead, co-integration is found between Zimbabwean and South African prices under the controlled trade regime.

**Table 2.15: Results of the Pesaran Shin Smith Bounds F test under a restricted trade regime**

| Dependent | Independent | F-Statistic | F-Stat bound (10%) | | F-Statistic decision | Implication |
|---|---|---|---|---|---|---|
| | | | Lower | Upper | | |
| Zimbabwe: Harare | Zambia: Lusaka | 3.54 | 4.04 | 4.78 | Accept | No Co-integration |
| Zimbabwe: Harare | South Africa: Randfontein | 5.35 | 4.04 | 4.78 | Reject | Co-integration |

**Table 2.16: Results of the Pesaran Shin Smith Bounds T test under a restricted trade regime**

| Dependent | Independent | T-Statistic | T-Stat bound (10%) | | T-Statistic decision | Implication |
|---|---|---|---|---|---|---|
| | | | Lower | Upper | | |
| Zimbabwe: Harare | Zambia: Lusaka | -2.52 | -2.57 | -2.91 | Accept | No co-integration |
| Zimbabwe: Harare | South Africa: Randfontein | -3.25 | -2.57 | -2.91 | Reject | Co-integration |

The findings from the bounds tests conducted under both the open and controlled trade regimes are significant in that they point to the influence that discretionary trade policies from government can have on the efficient operation of markets. Though multiple authors have found that trade-flow is not necessary for price transmission between markets, findings suggest that price transmission patterns are influenced by policies that inhibit trade.

### 2.5 Conclusions

The agricultural sector in ESA has undergone significant changes over the past decade, as growing income levels, rapid population growth and continued urbanisation expanded the demand for food products. This expansion was also evident in maize, which represents a critical food staple in the region. Due to its connotations with food security, the maize sector has been prioritised from a policy perspective and production in many countries has expanded rapidly. Differences in production expansion rates induced changes to trade patterns, which in turn have the potential to alter price relationships.

In light of the changes that occurred in the region, the purpose of this chapter was two-fold. Firstly, to provide context regarding the evolution of maize markets and the factors that influence them over the past decade, thus providing the clear point of departure required for forward looking analysis and a fundamental understanding of markets required for accurate model specification. Secondly, it provides an in-depth evaluation of price formation in the Southern African region, adding to the existing literature base on price relationships, but specifically also quantifying the impact that trade volumes, as well as trade inhibiting policies can have on efficient price transmission between markets.

Quantification of price transmission between different markets in the region was conducted in two parts, to allow separation of trade volume and trade policy impacts on price transmission parameters. Results of the trade defined regimes indicate that many markets in the region are subject to different long run price transmission and short run adjustment rates at varying levels of trade, but that policy impacts also need to be considered. Evaluation of the policy defined regimes were indicative of changes to long run equilibrium price relationships under open trade and trade controlled scenarios. A long run relationship between Zimbabwean and Zambian prices was established under an open trade regime, but not in a trade controlled regime. Conversely, a long run relationship between South African and Zimbabwean prices was confirmed in the regime where Zambian exports are controlled, but not in the regime where Zambia trades freely.

In most cases, the short-term adjustment towards long run relationships was faster under high trade regimes. Similarly, under an open trade regime, price transmission from Zambia to Zimbabwe was found to be fairly efficient, with a half-life of 2.77 months, but significantly slower under a controlled trade regime. Interestingly, price transmission from South Africa to Zimbabwe under periods when Zambia imposed export controls was found to be more efficient than that between Zambia and Zimbabwe under periods of open trade. A possible reason could be that most trade from South Africa to Zimbabwe occur through the private sector, whereas a large share of trade from Zambia to Zimbabwe often occurs through the governments food reserve agency.

Chapter 2 addressed a number of hypothesis, confirming the existence of long-run co-integration between markets where trade typically occurs, as well as the non-linearities associated with such relationships as a result of volatile trade levels and policy application. Whilst multiple authors have noted that trade is not necessary for prices to be transmitted from one market to another, findings suggest that trade volumes, as well as policies that inhibit trade periodically influence price transmission rates and long run relationships between markets.

Poor goodness of fit from the estimated parameters suggests that, in addition to neighbouring markets connected by trade, a number of domestic market factors such as supply and demand dynamics also influences domestic price movements. Direct relation of supply and demand dynamics, which are reported annually, is complicated by temporal aggregation effects and therefore not included in the econometric analysis. Nonetheless, the information provided by the price transmission analysis is critical to understanding price formation in the region and underpins the choice of model structure detailed and applied in the rest of the study.

# 3. TRADE FLOW SPECIFICATION AND PRICE FORMATION

## 3.1 Introduction

Price transmission has provided ample diagnostic tools for evaluating price relationships between markets and its application has provided transmission elasticities which account for non-linearity across multiple regimes. However the extent to which these complex interactions between markets have been captured into simulation models is distinctly limited. Within a simulative framework, Meyer *et al.* (2006) addressed the issue of multiple regimes through the introduction of an automated regime switching feature in a partial equilibrium model of South African agriculture, yet wider consideration of multiple trade regimes and associated price transmission patterns within simulation models relying on price linkages remains limited. Challenges related to temporal aggregation may be an important reason for this, yet the illustrated prevalence of multiple regime switches and implied non-linearity of price transmission remains a significant mismatch in relation to the linear price transmission elasticities typically imposed within net trade based simulation models.

This chapter reviews relevant literature related to market linkages and trade-flow incorporation in different simulation models. It also provides the context and theoretical basis for a methodology that models trade-flow as a system of behavioural equations, allowing multiple markets to interact simultaneously without losing domestic supply and demand dynamics in the price formation process. The inclusion of threshold variables that render trade-flow more elastic when breached further presents an alternative methodology to Meyer *et al.* (2006) to account for different trade regimes.

## 3.2 Review of trade and price formation in different modelling frameworks

Across the spectrum of quantitative models applied to policy related simulations, differences in the structure of trade-flow incorporation and price linkage methodologies are mainly attributed to the assumptions regarding product homogeneity and the extent of spatial explicitness. Broadly, simulation models are categorized into CGE and Partial Equilibrium models, each of which is characterized by specific strengths and weaknesses. In deciding which is more appropriate for specific analysis, analysts need to weigh the desire for broad country, sectoral and product coverage, with the need to incorporate detailed and accurate coverage of particular markets and policies (Westhoff, Fabiosa, Beghin & Meyers, 2004). Consideration of trade-related policies should also balance the need for spatially explicit analysis, which is more typical in a CGE framework. For this study, the focus on maize, as well as the need for detailed policy inclusion and evaluation renders the partial equilibrium model more appropriate. At the same time, the complex market interactions described within the region, combined with the isolation from the world market suggests that spatially explicit market linkages will be required to present a complete picture of price formation.

Spatially explicit features are not typical in partial equilibrium models (Van Tongeren *et al*., 2001), which tend to be specified in terms of net trade, implying that products are assumed to be homogeneous with no differentiation by country of origin. Models assume a single representative world price and trade occurs within a central pool. Domestic prices are typically derived from the world price through linear price transmission elaticities (Witzke *et al.,* 2011). By implication, unless a country is large enough for its supply and demand conditions to influence world price levels, the impact of its domestic price on surrounding regional markets will remain unaccounted for.

On occasions when spatially explicit features are included in a partial equilibrium framework, two different approaches can be identified, the use of which is dependent on assumptions associated with product homogeneity. At opposite ends of the scale, the spatial equilibrium approach assumes perfect homogeneity, whereas the so called Armington approach differentiates products based on country of origin, implying that the law of one price is no longer required to hold. Both approaches have specific strengths and weaknesses which influences relevance for specific analysis.

### 3.2.1 Homogeneous products and the spatial equilibrium condition

The spatial equilibrium approach was first formalised by Samuelson (1952) and further developed by Takayama and Judge (1971). It is characterized by a simultaneous equilibrium in different markets over time and space. The theory is based on maximization of a quasi-welfare function defined as the sum of producer and consumer surplus in each market after subtracting transport and storage costs. Consequently, price differences in each region cannot exceed the cost of transporting goods between regions and price differences across time cannot exceed the cost of storage. The price of product *i* in region $s$ can be described as follows:

$$P_{is} \leq P_{ir} + T_{irs} \tag{4}$$

This spatial arbitrage condition is also known as the weak law of one price, in that price differences can be smaller than the cost of trade. In addition to strict homogeneity, the model is based on strong assumptions of price taking and perfect information. For each pair of regions included in the model, one of three regimes is possible:

- No trade at all because price differences are smaller than transportation costs
- Positive trade from region r to region s and $P_{is} = P_{ir} + T_{irs}$
- Positive trade from region s to region r and $P_{ir} = P_{is} + T_{isr}$

Changes in the supply and demand conditions within any market in the region can potentially result in a switch from one regime to another, in which case price changes will not be fully passed on from the region where the shock occurred to another. In the case where price movements cause a switch in regimes, a small price change may invoke significant changes to predicted bilateral trade-flows. If the cost of transportation rises with the volume of trade however, prices will not be transmitted fully from one region to another even under stable regimes (Fackler & Goodwin, 2001).

Given the abundance of literature related to imperfect price transmission between spatial markets, as well as the frequent occurrence of both imports and exports into multiple countries in historic trade data suggests that the assumptions associated with the spatial equilibrium model are very restrictive, resulting in infrequent use for projection purposes and bilateral trade analysis (Abler, 2007). Nonetheless, the ability to invoke switches from one regime to another is efficient in replicating volatile trade-flow patterns, as well as inducing trade where none has occurred historically (Dillen & Gay, 2014; Nolte, 2006;). Within ESA, these are particularly desirable attributes, especially if imperfect price transmission and the occurrence of bidirectional trade can be incorporated.

### 3.2.2 Heterogeneous products and the Armington assumption

Product heterogeneity has been offered as a solution to the frequency with which two-way trade occurs in historic data. In this regard, the so-called Armington assumption (Armington, 1969) has been a popular solution within CGE models and can be interpreted as a multi-level utility function with imperfect substitution between similar goods from different origins. Typically derived from a Constant Elasticity of Substitution (CES) utility function, demand is modeled as a two-stage budgeting problem, determining first the budget shares associated with the total product group, before allocating budget shares to different origins (Figure 3.1). Within the partial equilibrium framework, where utility maximization is not explicitly modeled subject to a budget constraint, the two step process of the Armington structure first determines total demand as a function of income and prices, with prices reflecting a weighted average of products from different regional origins. In a second step, the composition of imports from different regions is determined based on the CES utility function (Britz, Witzke, Adenauer, Helming, Jansson & Gocht, 2014).

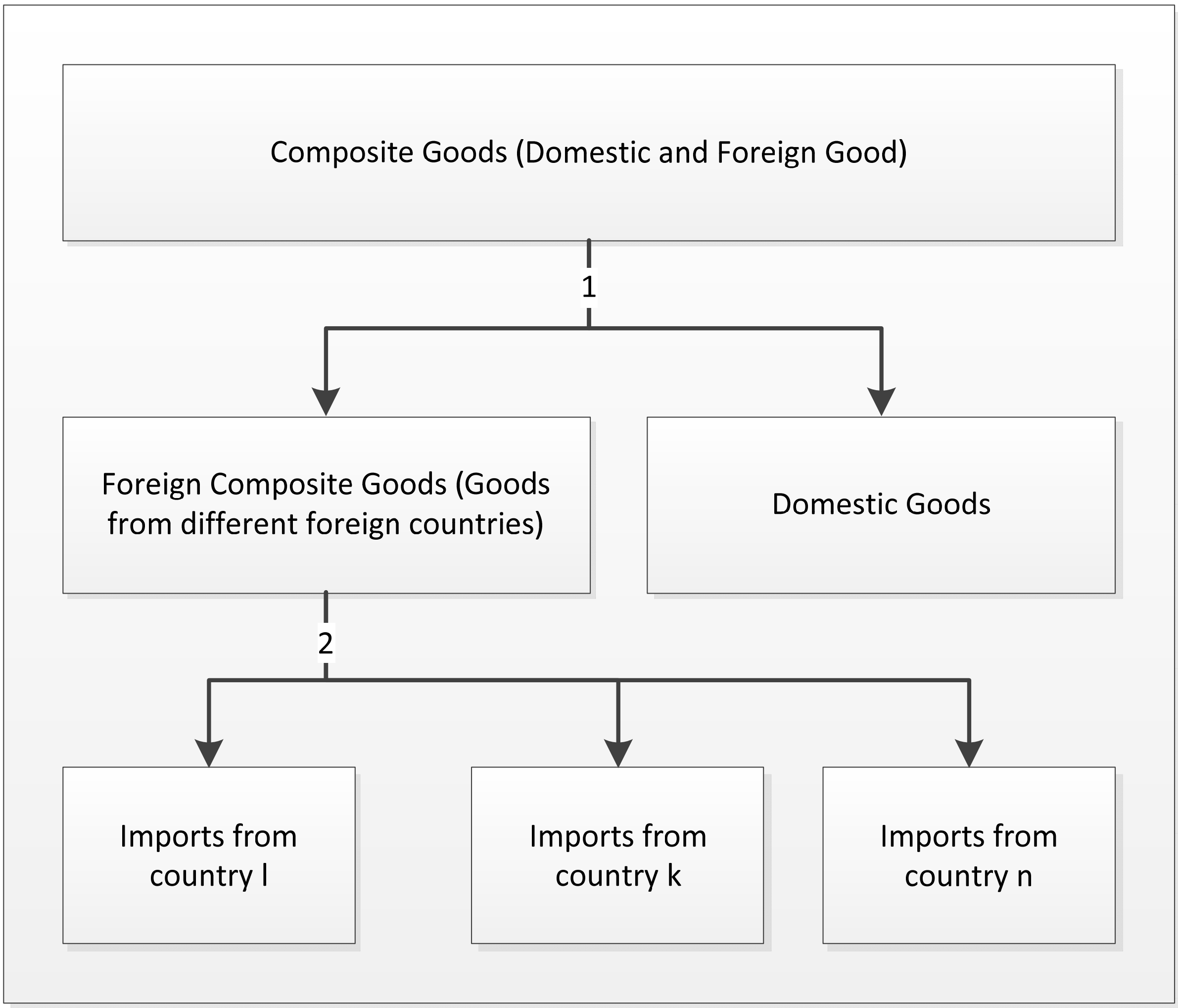

**Figure 3.1: Modeling of import demand with an Armington specification in a CGE context**
*Source: Kuiper & Van Tongeren (2006)*

Whilst useful for simplicity, the CES assumption is also responsible for the biggest shortcoming associated with the Armington specification. The so called ‘small shares stay small’ problem arises from the fact that incentive prices are calculated as volume weighted shares of domestic and imported goods, therefore if trade in the base period is a very small share of total consumption, it remains a very small share, as it can only increase relative to the initial share. The small share problem is illustrated by Kuiper and Van Tongeren (2006) using an import demand function from various foreign origins, derived from the optimization of CES preferences as below:

$$\frac{X_i}{X} = \alpha_i \left(\frac{P_i}{P}\right)^{-\sigma} \tag{5}$$

Where $X_i$ represents imports originating from country *i,* whilst X is the total imports, $\alpha_i$is a share parameter and σ is the common and constant elasticity of substitution between different foreign sources by which the CES function is defined. The price index for imports X can be expressed as follows:

$$P = (\sum_i \alpha_i P_i^{1-\sigma})^{\frac{1}{1-\sigma}} \qquad (6)$$

By normalizing all prices to 1, the share parameter $\alpha_i$ can be derived directly as the ratio of imports from *i* to the total amount of imports, effectively the relative importance of imports from country *i* in total imports. The small share problem is created by calibrating $\alpha_i$on trade-flows in the base period. In an extreme case, where $\alpha_i$is zero in the base period due to prohibitive trade restrictions, even the complete removal of trade barriers will not result in any trade-flow, as $\alpha_i$ will be set to zero. In a situation where $\alpha_i$ is positive but very small in the base period, a significant increase in $P_i$ will not cause a large change in $X_i$, regardless of the value of σ. Hence even when ambitious trade liberalization impacts are simulated, trade creation impacts are often understated (Sanjuan-Lopez & Resano-Ezcaray, 2015; Kuiper & Van Tongeren, 2006; Nolte, 2006).

Several solutions have been proposed for the small share problem, including replacement of initial zero trade with small numbers, increasing the elasticity of substitution and aggregating regions. The problems with such solutions are clear; changes to the elasticity of substitution will also affect other regions where initial trade shares are larger, whilst aggregation limits the extent of the analysis. Alternative solutions relate to changes in the functional form to a Constant Ratio Elasticity of Substitution Homothetic Function (Hanslow, 2001), which allows the elasticity of substitution to adapt to relative prices. Whilst this presents a solution to the small share problem by allowing flexibility in substitution elasticities, it still does not enable trade to be initiated from 0. Other studies have dealt with the problem by moving away from the CES function altogether, replacing it with a more flexible demand structure such as the Almost Ideal Demand System (AIDS) model (Weyerbrock, 1998; Robinson, Burfisher, Hinojosa-Ojeda & Thierfelder, 1993), however the main reason for applying the AIDS structure relates to reducing the terms of trade effects and the extent to which it allows small trade flows to expand remains unclear (Kuiper & Van Tongeren, 2006). The use of alternative functional forms greatly increases the number of parameters required, which has inhibited their use in the past (Nolte, 2006). Within a partial equilibrium framework however where optimization decisions are not explicitly modeled, the impact of such structural adjustments could be replicated through flexible elasticities on the parameters that drive import volumes.

The most recent solution to date was first proposed by Kuiper and Van Tongeren (2006), before further refinements by Philipidis, Resano-Ezcaray & Sanjuan-Lopez (2013) and Sanjuan-Lopez & Resano-Ezcaray (2015). The solution relates specifically to trade liberalization scenarios and proposes a two stage process which first estimates a gravity equation for trade-flow between specific country pairs where liberalization occurs, in order to estimate the initial trade creation impact. In a second step, this impact is embedded in the dataset as a ‘trade technology shock’ which increases the initial trade shares, before allowing the model to simulate the remaining welfare effects. Whilst providing a theoretically consistent solution for trade liberalization scenarios, the methodology is dependent on the anticipation of specific shocks for which gravity equations are estimated. This is acceptable for tariff reductions between specific countries, but for any other market related shift, such as increased productivity in a single country which moves it from a net importing to a net exporting regime, trade impacts will still be subject to the small shares problem and significant price changes will not induce trade-flow that has not previously occurred.

### 3.2.3 Gravity models for trade analysis

Gravity models are very popular in trade policy analysis, yet apart from providing a plausible solution in alleviating the small share problem within the Armington specification, they are not typically included directly in a simulation context. Named after Newtons theory of gravitation, it is proposed that the volume of trade between any two countries will be positively related to the size of their economies and inversely related to the trade costs between them. The use of gravity models has been particularly popular in investigating the impacts of preferential trade agreements, arguing that the inclusion of an additional dummy variable captures variations in the levels and direction of trade arising from the formation of the trade agreement. Popularity is rooted in its strong theoretical underpinning that is consistent with multiple prominent trade theories such as the Ricardian and Hoekser-Ohlin model, as well as its strong explanatory power when related to bilateral trade-flows (Teh & Piermartini, 2005).

Through the inclusion of trade costs (proxied by distance) and policy related dummy variables, gravity models have been very successful in explaining the distribution of trade between countries and therefore aid in reflecting the degree of substitutability between traded goods. They have been less successful in quantifying the impact of policy changes on overall trade levels in any single country. Conclusions related to welfare implications should be cautiously drawn, as these models may illustrate that trade volumes between specific countries have increased following policy implementation, yet they fail to differentiate between trade creation and trade diversion, which have significantly different welfare implications. Hence the gravity model measures trade effects, but fails to account for welfare effects (Teh & Piermartini, 2005). Used in combination with a simulation model as suggested by Kuiper and Van Tongeren (2006) the gravity equation is only required to initiate trade, after which welfare implications are simulated within the CGE or partial equilibrium model.

### 3.3 Applicability of different methods to maize markets in the ESA region

Regardless of the approach used, inclusion of bilateral trade-flows in the modeling framework is clearly subject to a number of constraining assumptions. In choosing between the different methodologies, decisions therefore need to be made as to which of these assumptions are more relevant to the products and questions that one seeks to answer. One must not lose sight of the fact that models are rough approximations of the real world, as opposed to exact replications and must therefore ultimately be judged on the degree to which it answers the questions that it was designed to address (Boland, 1989).

Within the context of this study, the focus on maize suggests that assumptions of homogeneity could be plausible, particularly related to intra-regional trade of white maize produced for human consumption, which would only be subject to minor quality differences. Consideration of maize in the world market makes this assumption less plausible however, as the majority of surplus maize in the global market would be yellow maize produced primarily for consumption as animal feed. Furthermore, legislation related to the use of GM technology would prevent the bulk of such yellow maize from entering the region, whilst also removing a substantial share of South African maize from the regional market. Inclusion of bilateral trade within the region whilst considering the rest of the world in a non-spatial context allows the regional product to be differentiated from the product traded in the global markets.

Relaxation of the homogeneity assumption would suggest that an Armington like specification is more appropriate and it has also been applied in the PETS model maintained by IFPRI, yet the small share problem remains an issue that cannot be ignored. Whilst the combination of a gravity equation and a CGE or partial equilibrium model does provide a plausible solution when simulating trade liberalization effects (Sanjuan-Lopez & Resano-Ezcaray, 2015; Kuiper & Van Tongeren, 2006), it fails to correct for the trade creation effects of a regime switch from net imports to net exports that could be induced by domestic supply and demand dynamics in a country. Within the dynamic ESA region, such impacts are important considerations, as illustrated by the evolution of the Zambian maize market and the frequency with which countries such as Malawi move from net importing to net exporting scenarios.

Literature suggests that the Armington specification performs well when trade flows are relatively constant (Dillen & Gay, 2014; Witzke *et al.*, 2011; Nolte, 2006), however the historic volatility in trade patterns within the ESA region (Figure 3.2) suggests that a spatial equilibrium approach, which is able to shift from one regime to another, will be more successful. Two-way trade is however also prevalent in historic trade data, which is problematic within the spatial equilibrium framework.

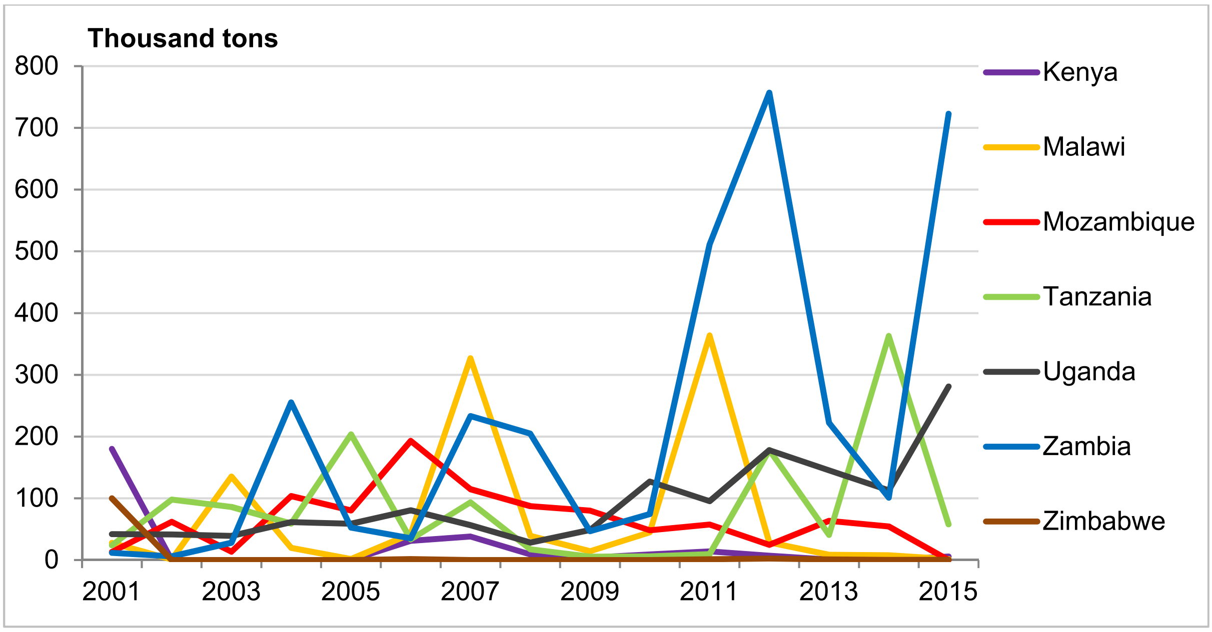

**Figure 3.2: Maize exports from ESA (excl. South Africa)**
*Source: Compiled from ITC Trademap (2017) and FEWSNET (2016)*

The restrictiveness of the spatial equilibrium approach has limited its use for bilateral trade simulations, yet its effectiveness can also be linked to the level at which spatial explicitness is accounted for. Spatial equilibrium theory considers a market to be a single point in space, resulting in the restriction of no two-way trade, yet simulation models are typically presented at country level. Considerations of trade-flows at country level implies that multiple markets (cities) could be included in a single country and given the size of most countries in the region, as well as the high cost of transportation, trade could flow into and out of a single country in different places as a result of optimizing transportation costs between surplus and deficit markets. At national level, this would allow bidirectional trade without violating the spatial equilibrium condition.

### 3.4 Proposed structure of the trade model

An appropriate model that captures salient market features and complex interaction in the region will consider multiple market linkages and non-linearity of price transmission between different markets. Therefore, spatially explicit bilateral trade-flows will be incorporated into the traditional partial equilibrium structure. In light of historic volatility reflected in intra-regional trade flow in ESA, the structure employed in this model relates closely to the spatial equilibrium approach, which has been proven more successful than the Armington structure in modeling volatile trade patterns (Dillen & Gay, 2014; Nolte, 2006) and is not subject to the small share problem.

The spatial equilibrium condition implies that the price difference between two regions cannot exceed the transaction costs associated with trade between them. Traditionally, it is incorporated into a partial equilibrium framework through direct price linkages, where prices are either transmitted fully between countries, or based on pre-estimated price elasticity. In this instance, markets are cleared through trade, hence excess supply (demand) is exported (imported) to the world market and products are considered perfectly substitutable. By implication, domestic supply and demand fluctuations would influence trade levels, but will have no impact on domestic prices. This is appropriate when trade patterns are fairly regular, yet when dramatic changes in domestic supply and demand conditions cause markets to switch between various regimes, moving from net imports, to autarkic or even net export scenarios, greater flexibility in price formation and model closure is required (Meyer *et al.,* 2006).

Markets trading under 'near autarkic' regimes defined by Meyer *et al.* (2006) as a type of 'regional autarky isolated from world markets' are more appropriately cleared based on equilibrium pricing – a price where total supply is equated to total demand. In this case, trade-flow is modeled as behavioural equations and it is assumed that arbitrage conditions would push the two markets towards the spatial equilibrium condition. Hence exports from region *i* to region *j* ($E_{ij}$) could therefore be specified as follows:

$$E_{ij} = \begin{cases} 0 \; if \; P_j < (P_i + T_{ij}) \times (1 + TR_{ij}) \\ \beta_1(P_j - (P_i + T_{ij}) \times (1 + TR_{ij})) \; if \; P_j > (P_i + T_{ij}) \times (1 + TR_{ij}) \end{cases} \quad (7)$$

Where $T_{ij}$ relates to the cost of trade from region *i* to region *j,* $TR_{ij}$ refers to the import tariff in region *j* applied to products originating from region *i.* If the trade-flow correction parameter ($\beta_1$) is infinitely large, the weak law of one price would be enforced and the spatial arbitrage condition would hold. Factors such as time required in exploiting arbitrage conditions, policy implementation, infrastructural restraints, imperfect information and agent expectations related to price movements all contribute to finite elasticities. The resulting imperfect substitution is embedded in the parameter $\beta_1$, which imposes the strength of the arbitrage correction. Literature has confirmed that the size of deviations from equilibrium conditions between markets influence the rate of adjustment (Goodwin & Piggot, 2001), which suggests that the strength of adjustment should not be fixed. Flexibility in the strength of adjustment towards the arbitrage condition can be introduced through a constant threshold variable ($k_{ij}$) that would result in a much larger arbitrage correction if breached, in which case $E_{ij}$ can be specified as follows:

$$E_{ij} = \begin{cases} 0 \; if \; P_j < (P_i + T_{ij}) \times (1 + TR_{ij}) \\ \beta_1(P_j - (P_i + T_{ij}) \times (1 + TR_{ij})) \; if \; P_j > (P_i + T_{ij}) \times (1 + TR_{ij}) \\ \beta_2(P_j - (P_i + T_{ij}) \times (1 + TR_{\mathrm{ij}}) - k_{ij}) \; if \; P_j - k_{ij} > (P_i + T_{ij}) \times (1 + TR_{ij}) \end{cases} \tag{8}$$

In this case, the arbitrage correcting parameter beyond the threshold ($\beta_2$) would be much larger than $\beta_1$. The remaining challenge with imposing strict spatial arbitrage conditions is embedded in temporal scale; the partial equilibrium model used for simulations is an annual model, whilst trade occurs on a daily basis and the response to conditions of spatial arbitrage takes time (Goodwin & Piggot, 2001). Hence while annual average prices may not be indicative of spatial arbitrage, trade may still be observed due to periods in the year when relative prices were conducive to trade. Consequently, an additional threshold parameter may need to be introduced to allow trade to occur close to the occurrence of spatial arbitrage, as opposed to only occurring when spatial arbitrage holds strictly on an annual basis. Under this condition, the behavioural equation could be specified as follows, with $m_{ij}$ reflecting the additional threshold:

$$E_{ij} = \begin{cases} 0 \; if \; P_j + m_{ij} < (P_i + T_{ij}) \times (1 + TR_{ij}) \\ \beta_1(P_j - (P_i + T_{ij}) \times (1 + TR_{ij}) + m_{ij}) \; if \; P_j + m_{ij} > (P_i + T_{ij}) \times (1 + TR_{ij}) \\ \beta_2(P_j - (P_i + T_{ij}) \times (1 + TR_{ij}) - k_{ij}) \; if \; P_j - k_{ij} > (P_i + T_{ij}) \times (1 + TR_{ij}) \end{cases} \tag{9}$$

The suggested specification is presented as an alternative methodology to replicate a switch in regime that introduced by Meyer *et al.* (2006), without linking any prices directly. In avoiding direct price linkages, instead allowing transmission between markets to originate from trade volumes, interactions between multiple markets can be simulated simultaneously. As suggested by Meyer *et al*. (2006), the absence of trade would imply that price transmission is weak, with domestic prices being influenced by domestic supply and demand conditions. Arbitrage conditions would however result in some trade-flow and imply transmission from market *i* to market *j,* whilst a breach of the threshold would allow trade-flow to become significantly more elastic, implying a higher degree of price transmission between markets. Should relative prices shift to the extent that a country moves from a net importing to an autarkic or even net exporting position, the proposed setup would allow enough movement in prices for this to occur, whilst also allowing for impacts on other countries in the region. By implication, the specification would allow for stronger future price transmission between markets where it is historically weak if trade is initiated from very low levels. This would not be the case if a pre-estimated price transmission is imposed through direct price linkage.

### 3.5 Trade-flow parameters

The proposed structure of the trade equations allows for greater flexibility in terms of market interaction, but poses challenges related to parameterization. The difficulty of obtaining robust estimates without good data on both prices and trade volumes has been noted (Brooks & Melyukhina, 2005), whilst Bac, Chevet and Ghysels (2001) considered themselves hampered by only 40-50 years of observed data to conduct co-integration tests. At the same time, it provides the only information regarding parameters, as the structure of the trade flow equations has not been adopted before and hence elasticities and threshold levels would not be available in existing literature.

Within most of the countries covered in this analysis, price and bilateral trade data is only obtained from 2005 onwards, providing only 10 annual observations. In some cases, data is available from 2001, resulting in 14 annual observations. Consequently, estimation of threshold levels and parameters will only be viable at an increased frequency, based on monthly or quarterly data. Naturally, this introduces temporal effects when thresholds are applied to annual data, however quarterly estimation provides a starting point for consideration and must be considered more efficient than purely synthetic parameters.

Based on monthly and quarterly data, the methodology proposed by Hansen (2015) for a case where the regression function is continuous, but the slope has a discontinuity at a threshold point that is unknown can be applied to estimate the parameters of the trade equations. The theoretical equation can be illustrated as follows:

$$Y_t = \beta_1 ( x_t - \gamma )_- + \beta_2 ( x_t - \gamma )_+ + \beta_3' z_t + \mu_t \qquad (10)$$

Where $Y_t$, $x_t$ and $\mu_t$ are scalars and $z_t$ is a vector which includes an intercept. $Y_t$ in this instance represents trade volumes, whereas $x_t$ represents the price difference between the surplus and deficit market, after accounting for transportation costs and applied tariffs. The “positive part” and the “negative part” of a real number a is denoted by $(a)_-$ = min(a,0) and $(a)_+$ = max(a,0). The parameters can then be estimated so that $\beta_1$represents the slope of $x_t$ for values $x_t < \gamma$, whilst $\beta_2$represents the slope of $x_t$ for values $x_t > \gamma$. The regression function remains continuous in the variables x and z, but the slope with respect to x is discontinuous at x = $\gamma$. Within the context of this study, the proposed model will allow the estimation of a threshold that changes the strength of the arbitrage correction factor through a least squares regression, whilst also presenting a test for the threshold effects within the price difference variable. Additional explanatory variables such as dummy variables to account for seasonality or export control measures can be included as part of the vector z.

Data challenges remain, firstly in the sense that unrecorded informal trade is not captured in the data and therefore unaccounted for. The Famine Early Warning System Network (FEWSNET) captures some informal trade numbers through enumeration at various border points in the region, which are added to formally reported volumes, but admittedly this is a mere estimate and a small share of actual informal trade flows. FEWSNET estimates indicate that they capture roughly 80% of the trade between Mozambique and Malawi and roughly one third of the trade occurring between Zambia and the DRC. Furthermore, transportation rates for some routes are obtained from Commodity Insight Africa surveys, but coverage and time series is limited, hence a large share of the transportation rates adopted are based on extrapolation over time based on a combination of Gross Domestic Product (GDP) inflation and oil prices, as well as extrapolation over different market pairs based on distance.

Whilst the solution is not optimal due to aforementioned data challenges and temporal aggregation effects from monthly or quarterly to annual data, it will validate the appropriateness of including a threshold in the trade equations, whilst also providing a starting point from which annual parameters can be adjusted synthetically. In order to provide information on thresholds and slope variables, estimations were conducted based on both monthly and quarterly data, using country pairs where significant trade has occurred in the past. Results are presented in Table 3.1, which also includes the critical value, as well as the associated p-value used to test for the validity of the kinked model, using the methodology proposed by Hansen (2015). In all cases, the kinked model provided a significant improvement over a normal regression at 10% level, which validates the use of thresholds in the trade equations.

**Table 3.1: Threshold and slope parameter estimation results in selected countries**

| Exporter | Importer | Frequency | Threshold | $\beta_1$ | $\beta_2$ | $W_{test}$ | P-value |
|---|---|---|---|---|---|---|---|
| Uganda | Kenya | Monthly | 79.500 | 0.034 | 0.006 | 25.840 | 0.000 |
| Uganda | Kenya | Quarterly | 63.300 | 0.044 | 0.316 | 11.230 | 0.070 |
| South Africa | Zimbabwe | Monthly | 22.600 | 0.036 | 0.093 | 13.910 | 0.005 |
| South Africa | Zimbabwe | Quarterly | 10.000 | 0.320 | 0.521 | 31.850 | 0.002 |
| South Africa | Mozambique | Monthly | 17.600 | 0.032 | 0.047 | 39.420 | 0.000 |
| South Africa | Mozambique | Quarterly | 30.800 | 0.102 | 0.159 | 30.490 | 0.002 |
| Zambia | Zimbabwe | Monthly | 37.200 | 0.032 | -0.046 | 8.870 | 0.020 |
| Zambia | Zimbabwe | Quarterly | 42.800 | 0.120 | -0.303 | 6.080 | 0.051 |

Assumptions regarding synthetic annual parameters in the trade equations are based on inspection of historic trade flows and price differences combined with knowledge about periods of trade controls. The estimations from higher frequency data provides a backdrop for these assumptions however and create context as a starting point. In many instances historically, trade started to occur before price differences exceeds 0, which can be ascribed to a number of factors including data quality and temporal aggregation effects – trade occurs daily and through periods of the year the difference may be positive and negative, resulting in some trade even when annual average prices suggest it should not have occurred. Thus, the point which initiates trade differs per trading pair and is represented in the theoretical structure in equation 9 by $m_{ij}$.

The assumptions associated with the price difference at which trade starts to occur ($m_{ij}$), the threshold point at which trade becomes more elastic ($k_{ij}$), as well as the slope below ($\beta_1$) and above ($\beta_2$) the threshold point are presented in Appendix 3, with a few selected pairs that have traded historically included for in Table 3.2. In selected cases, the inclusion of a second threshold parameter beyond which trade becomes even more elastic was required to improve goodness of fit. The second threshold is represented by $l_{ij}$ and the slope beyond the second threshold by $\beta_3$. As a general rule of thumb, a slope of 0.25 was applied below $k_{ij}$, increasing by a multiple of 10 to 2.5 above $k_{ij}$, with $m_{ij}$ at 20 and $k_{ij}$ at 10. This represents a more elastic specification that most estimated routes in order to keep price volatility at reasonable levels and ensure some price transmission between markets. Given that quarterly estimates yielded significantly larger elasticities than monthly estimates, as further increase in annual elasticities is justifiable. In the event that trade has occurred historically, the threshold and slope variables were adjusted as necessary to improve historic fit, accounting for periods of export controls. Export controls remain exogenous in the model; while the structure allows for such controls to be imposed in future scenarios, but they are not trigged automatically in the model.

**Table 3.2: Selected assumptions on export parameters**

| Exporter | Importer | $m_{ij}$ | $k_{ij}$ | $l_{ij}$ | $\beta_1$ | $\beta_2$ | $\beta_3$ |
|---|---|---|---|---|---|---|---|
| | | US Dollars | | | | | |
| South Africa: Randfontein | Mozambique: Maputo | 0 | 80 | 150 | 0.89 | 1.78 | 3.56 |
| South Africa: Randfontein | Zimbabwe: Harare | 30 | 0 | NA | 1.80 | 9.00 | NA |
| South Africa: Randfontein | Other | 80 | -60 | NA | 5.45 | 32.70 | NA |
| Tanzania: Arusha | Kenya: Nairobi | 20 | 10 | 40 | 0.30 | 2.40 | 7.20 |
| Uganda: Kampala | Kenya: Eldoret | 30 | 20 | NA | 1.20 | 8.40 | NA |
| Zambia: Lusaka | Malawi: Lilongwe | 30 | -15 | NA | 0.47 | 2.35 | NA |
| Zambia: Lusaka | Zimbabwe: Harare | 20 | 0 | 10 | 1.20 | 12.0 | 24.0 |

Given that in many market pairs, trade has never been initiated, many of the parameters are speculative, but provide the opportunity for trade to start occurring should drastic shifts in relative price occur. Parameter refinement will always be possible, but in instances where trade has occurred historically, the specification captures turning points well, as illustrated by Figure 3.3, which shows South African exports from 2005 and 2015.

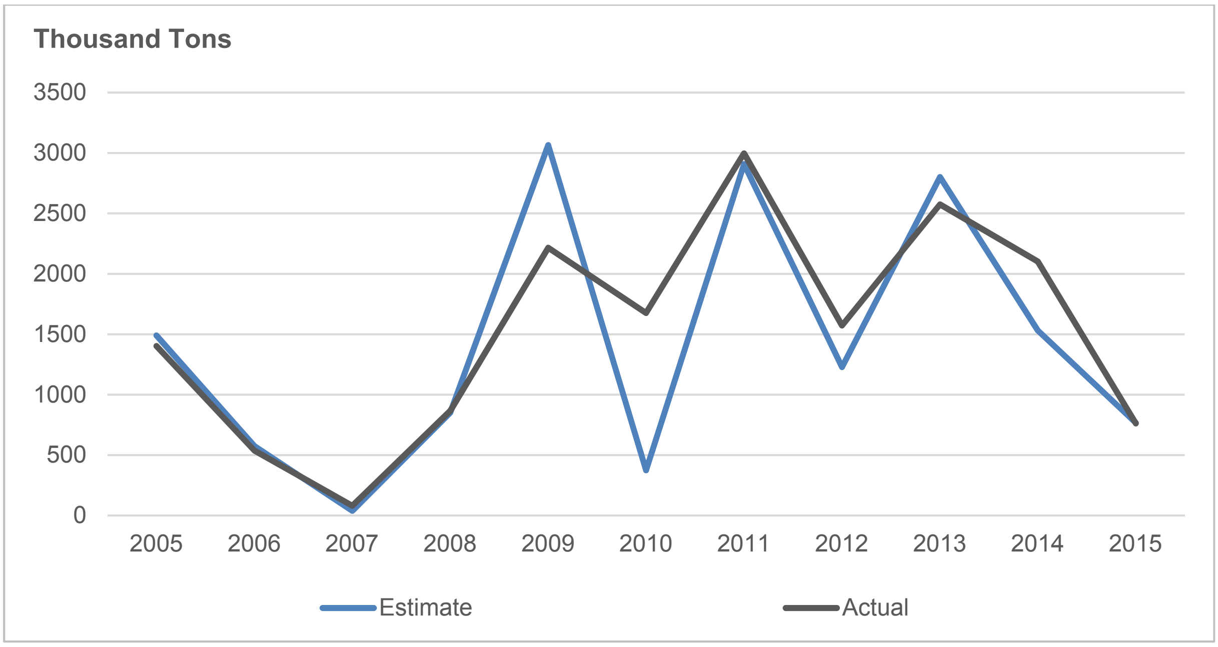

**Figure 3.3: Total South African maize exports - actual vs. estimate 2005 - 2015**

Intra-regional imports are not modelled explicitly, but rather assumed to be equal to exports from the relevant trading pair, as a countries exports to another would be equal to the partners imports by definition. Consequently, the only import equation in the model relates to imports from outside of the modelled region. Specification is the same as in the export equation, based on differences to the world price and parameters are presented in Appendix 3.

## 3.6 Price formation

The proposed model structure determines prices as a function of total supply and total demand, with trade providing influence from world and regional prices. Prices are therefore the result of the solution obtained from the entire system of equations. Figure 3.4 presents a flow diagram illustrating endogenous variables in blue and exogenous variables in white. Net trade by country and its impact on domestic prices (enclosed) is expanded in Figure 3.5 to enable illustration of more detail, but with the inclusion of only 3 countries for simplicity.

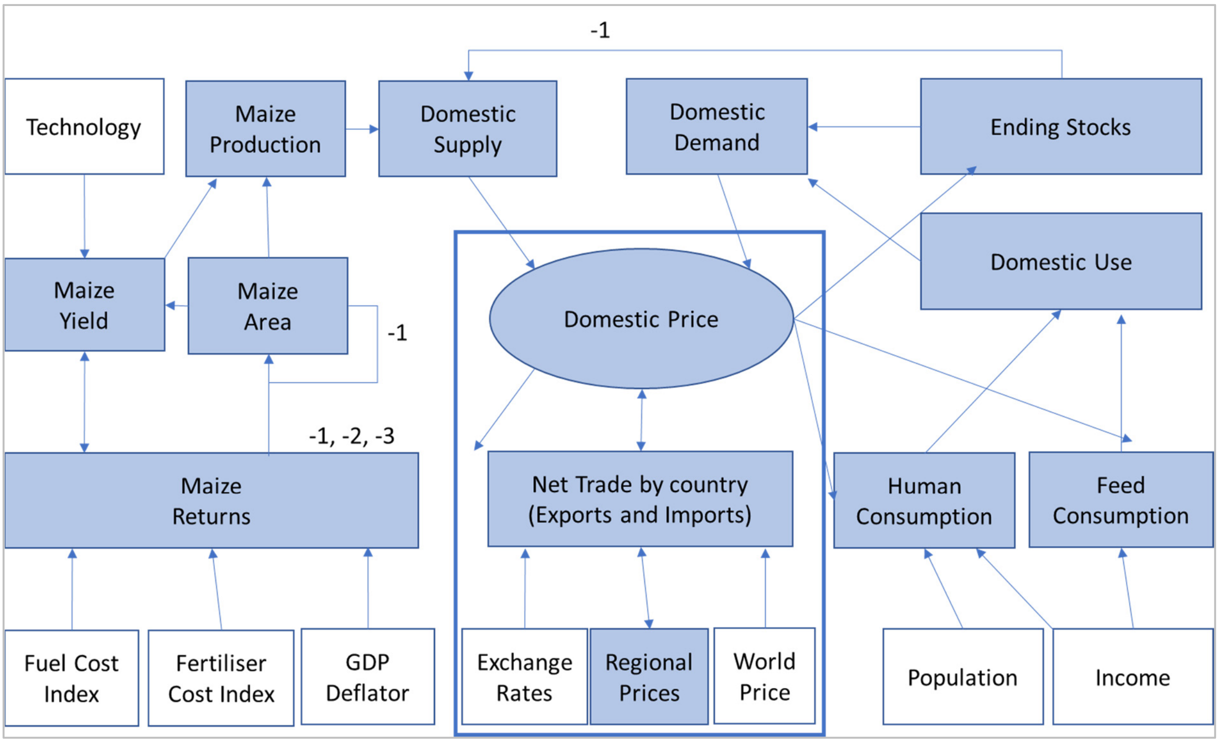

**Figure 3.4: Flow diagram of model structure and price formation**

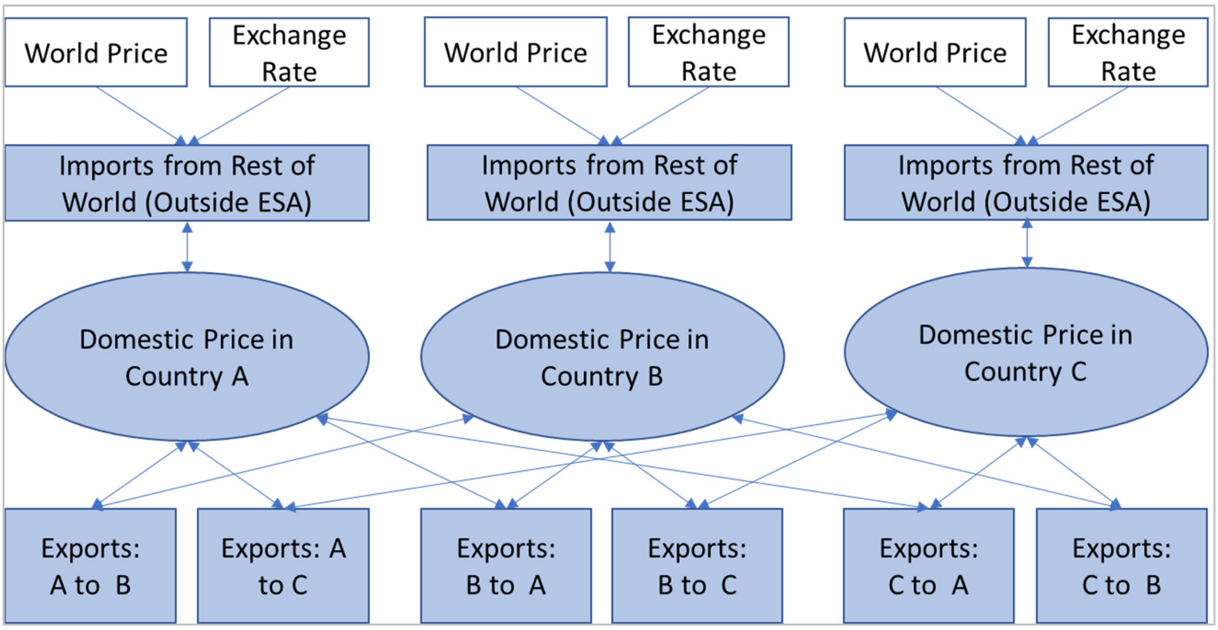

**Figure 3.5: Flow diagram of the trade impact on the price solution**

Table 3.2 indicated that within the trade-flow equations, different regional prices within each country are considered for trade with specific partners, based on its typical status as surplus or deficit market within the country and geographic proximity to trading partner. The price solution is however based on a single important market within each country (except for Mozambique which is closed on a national average price) and transmitted to alternative regions through a price linkage equation. The relevant closing market, as well as the transmission elasticities to different regional markets in each country are presented in Table 3.3. Elasticities are estimated from monthly data used in the price transmission analysis in Chapter 2. In South Africa, a single Randfontein reference price is determined on the commodity exchange, but both yellow and white maize are traded. Closure is achieved through the yellow maize price, which is transmitted to white maize using an elasticity of 1.10 on the yellow maize price, as well as total maize production, as white maize prices are typically lower than yellow in a surplus year, but higher in a deficit year.

**Table 3.3: Price transmission between different regional markets within countries**

| Country | Closing market | Other price | Long term transmission elasticity |
|---|---|---|---|
| Kenya | Nairobi | Eldoret | 1.15 |
| Kenya | Nairobi | Mombasa | 0.99 |
| Malawi | Lilongwe | Mzuzu | 0.88 |
| Mozambique | National Average | Nampula | 1.12 |
| Mozambique | National Average | Maputo | 0.63 |
| Mozambique | National Average | Tete | 1.12 |
| Mozambique | National Average | Manica | 1.22 |
| Tanzania | Arusha | Mbeya | 0.82 |
| Tanzania | Arusha | Dar Es Salaam | 1.05 |
| Zambia | Lusaka | Choma | 0.57 |

## 3.7 Concluding remarks

This chapter provided a review of relevant literature, before proposing a modeling specification for the inclusion of bilateral trade in a partial equilibrium framework. The methodology considers some of the assumptions and concepts from both the spatial equilibrium and Armington approach, proposing a solution that is less rigid. Trade flow is modeled on the principles of spatial equilibrium, yet trade is not assumed to be perfectly elastic and regional market consideration allows bidirectional trade, addressing some of the shortcomings of the spatial equilibrium approach. The proposed system goes beyond the scope of traditional price transmission analysis as it considers multiple market interactions simultaneously, as opposed to multiple markets being linked to a single representative price.

Modeling market interactions through trade as opposed to direct linkage presents a solution that incorporates complex interactions between multiple markets, without losing domestic supply and demand impacts in each market. The inclusion of threshold variables that render trade-flow more elastic when breached accounts for non-linearity and multiple regimes evident in price transmission analysis, something that has largely remained absent from simulation models. In this regard, it closes the gap between retrospective econometric analysis of price transmission and the simplified structure of simulation models typically used for *ex ante* analysis by presenting a simulation model that more closely resembles the market conditions described by price transmission analysis.

# 4. DOMESTIC MARKET SPECIFICATION AND MODEL VALIDATION

## 4.1 Introduction

Having considered the extent of market integration in the region, as well as the existing methods of incorporating trade flow and price formation into market simulation models, Chapter 3 presented a structure that models trade flow in a bilateral context. The traditional partial equilibrium framework is adapted to include spatial aspects within the region and markets are linked through trade as opposed to direct price linkage. This allows different markets to interact simultaneously, whilst also allowing any one market to shift from a net import to a net export regime and accounting for the associated shifts in price levels.

This chapter presents the domestic market specification of the proposed trade linkage model, as well as a number of tests and simulations to validate it. Validation considers different factors, including simulation over an historic period, the ability to generate a plausible outlook, response to world price and domestic production shocks, as well as the ability to replicate historic volatility. In all these factors, the proposed model is compared to the result from a traditional price linkage equation, which provides a benchmark against which the proposed model's predictive power can be tested.

## 4.2 Model specification

The proposed simulation model can be described as a single commodity, dynamic partial equilibrium model for maize covering eight countries across ESA[8]. Domestic supply and demand equations are based on conventional specification, owing to the focus of this study on price formation and trade-flow dynamics. The lack of high quality, long term time series data related to commodity balance sheets, as well as the rapidly changing agricultural environment in the region support a synthetic calibration

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[8] The countries included in the simulation model are Kenya, Malawi, Mozambique, South Africa, Tanzania, Uganda, Zambia and Zimbabwe

approach as opposed to econometric equation estimation. Where possible, elasticities are obtained from existing literature, supplemented by economic theory and analyst judgment. This practice is often adopted given model size, identification problems and lack of, or poor quality data (Van Tongeren *et al.,* 2001). The model is therefore categorized as a simulation model as opposed to an econometric model, which would have included single equation estimation (Abler, 2007).

The synthetic parameters associated with a simulation model of this nature allows for the use of a shorter data series, but the quality of modeling results remain underpinned by the need for accurate supply and use balance sheets to be used for calibration. Concerns regarding the quality of agricultural statistics in SSA have been noted by multiple authors. Carletto (2010) indicates that, of the 44 countries in the region covered by the FAO, only two are considered to have high standards of data collection and standards in a further 21 countries remain low. Within the maize sector, ReNAPRI have compiled balance sheets for the eight countries covered in this study, from a variety of sources noted in Table 4.1.

**Table 4.1: Data requirement and sources**

| **Exogenous variables** | **Source** |
|---|---|
| Macro-Economic Variables | IMF, World Bank |
| World Prices for Agricultural Commodities | FAPRI |
| **Endogenous variables** | |
| Maize area, yield and production in individual countries | National Statistical Offices, FAO and USDA |
| Feed use, stock levels | National Statistical Offices, FAO and USDA |
| Trade volumes | National revenue services, ITC and FEWSNET |
| Human consumption | Derived as a balancing figure |

In addition to the supply and use balance sheets, the partial equilibrium nature and regional coverage implies that the model relies on projections for key exogenous variables, the sources of which are also presented in Table 4.1. Price data is calculated as annual averages of the monthly data obtained in the various regional markets for the price transmission analysis in Chapter 2.

While the supply and demand specification is simple by construction and in line with existing literature, inclusion of critical policies that influence market dynamics is prioritised. Policies specifically related to maize markets in the region are highlighted briefly in ReNAPRI (2014) and detailed in Chapter 2. Those prioritised for inclusion in the model are presented in Table 4.2.

**Table 4.2: Policies included in the modelling framework**

| Country | Input support programs | Strategic food reserve | Trade policy |
|---|---|---|---|
| Kenya | X | X | X |
| Malawi | X | X | X |
| Mozambique | | | X |
| South Africa | | | X |
| Tanzania | X | X | X |
| Uganda | | | X |
| Zambia | X | X | X |
| Zimbabwe | | X | X |

### 4.2.1 Domestic supply

In line with established methodology such as that employed by FAPRI (2011) and OECD-FAO (2015), domestic production is disaggregated into area and yield equations, with an identity to compute production levels. Consistent with the methodology employed by Meyer (2006) and OECD-FAO (2015), the bulk of the supply decision rests in the area equation. Whilst based on the assumption that producers will act rationally in order to maximize profit, the supply response is modelled as a reduced form equation and not as a direct profit maximization problem.

Meyer (2006) indicates that dynamic relationships are important in modelling agricultural markets, as biological cycles are inherent in the production process and in many cases, producer decisions are based on expectations. As such the most common approaches associated with supply estimations relate to partial adjustment and adaptive expectations. The Nerlovian supply model detailed in Meyer (2006) combines the partial adjustment and adaptive expectation models to estimate area harvested as a function of lagged area harvested and expected price. In this instance, the price variable is replaced by a variable of net returns in past periods, expressed as a ratio of gross returns to input costs. The returns variable represents the expected returns and enables the inclusion of policies such as fertiliser subsidies. The theoretical function is presented below:

$$MAZ_{AH} = \alpha + \beta_1 MAZ_{AH(t-1)} + \beta_2 MAZ_{RET(avg\ t,t-1,t-2)} + \mu \qquad (11)$$

Where:

$MAZ_{AH}$ is the maize area harvested as proxy for maize area planted
$MAZ_{RET}$ is the maize returns calculated as area*yield/Input cost index
$\mu$ is the residual

Input costs are expressed as a weighted index, based on typical input share allocations for fuel, fertiliser, seed and other. Such allocations vary across countries and assumptions are derived from a combination of literature and in country expert opinion. As all modelled countries are net importers of crude oil and fertiliser, the price indices for these products are derived from international prices, adjusted for currency fluctuations. In the case of seed, actual costs are available sporadically, with the remainder of the time series extrapolated from the GDP deflator as measure of inflation. Other input costs are also adjusted based on inflation, but separation of the seed component allows for the incorporation of input subsidy programs that also include seed. The relative share allocations for specific inputs are presented in Table 4.3.

**Table 4.3: Input cost index weight assumptions per country**

| Country | Fertiliser share | Fuel share | Seed share | Other |
|---|---|---|---|---|
| Kenya | 0.21 | 0.13 | 0.13 | 0.53 |
| Malawi | 0.44 | 0.13 | 0.19 | 0.24 |
| Mozambique | 0.20 | 0.13 | 0.25 | 0.42 |
| South Africa | 0.42 | 0.13 | 0.10 | 0.35 |
| Tanzania | 0.40 | 0.13 | 0.08 | 0.39 |
| Uganda | 0.18 | 0.13 | 0.08 | 0.61 |
| Zambia | 0.37 | 0.16 | 0.24 | 0.23 |
| Zimbabwe | 0.40 | 0.13 | 0.20 | 0.27 |

*Source: Wilson & Lewis (2015); ReNAPRI (2013); Burke, Hichaambwa, Banda & Jayne (2011); Nyoro, Kirimi & Jayne (2004);*

The starting point for supply elasticity assumptions in the simulation model is documented in ReNAPRI (2013), which is expanded to include Zimbabwe and Uganda, both of which are important countries when regional trade-flows are considered. The assumptions contained in ReNAPRI (2013) are homogeneous in nature and given the lack of information on Zimbabwe and Uganda, they are complemented by a comprehensive review of existing literature related to the supply response in relevant countries.

Within the first version of the model documented by ReNAPRI (2013), supply equations include a response to the price of alternative cereals. Given that such prices would be exogenous in the single commodity model proposed in this study and would therefore not react to supply and demand changes, they are omitted. Prices of substitutes typically move together at least to some extent as producers will adjust to relative price shifts. When substitute prices are included as exogenous variables, this link is effectively broken. Instead by omitting them, the combined response of both own price and cross price elasticities are captured in a less elastic own price elasticity than would be expected if substitute prices are included.

Multiple authors have evaluated the crop supply response across different countries in SSA, at various levels of aggregation. Magrini, Balie & Morales-Opazo (2016) note that the agricultural sectors aggregate supply response to prices is typically very inelastic. Using panel data techniques and a sample of 10 countries in SSA, the area response of basic cereal products to prices is estimated at 0.39. Focusing on grain area in South Africa, Meyer (2006) estimated the total summer grain area as a function of a 6-crop weighted sum of expected returns, rainfall and a fuel price index. The reported elasticity associated with returns was 0.22 and the elasticity associated with the fuel cost index was -0.11. Individual crop area was then estimated as a second step, based on the relative returns for maize and alternative crops. An elasticity of 0.37 was reported for maize.

Given its importance as core food staple, multiple studies have also focused on the supply response for maize in various countries in Southern Africa. Older work in Zambia (Foster & Mwanaumo, 1995) estimated a dynamic supply response, stipulating a short run price elasticity of 0.5 and a corresponding long run price elasticity of 1.57. As related to fertiliser prices, he estimated a short run elasticity of -0.48 and a long run elasticity of -1.44. The implied coefficient on the lagged area is 0.66. This study also omitted substitute prices as explanatory variables, instead opting to capture the entire system’s response in the maize elasticity. The estimations are old however which makes them less relevant given the changes that have occurred in the region since.

In South Africa, a very recent study by Shoko, Chaminuka and Belete (2016) estimated a Nerlovian partial adjustment model for maize, providing short and long run price elasticities of 0.24 and 0.36 respectively. Kapuya (2010) followed a more disaggregated approach in Zimbabwe, considering commercial and small scale communal producers separately. Short run price elasticities of 0.57 and 0.71 were reported for communal and commercial producers respectively. The coefficient on the lagged area variable was estimated at 0.13 and 0.11 for communal and commercial producers respectively, implying a long run elasticity of 0.66 and 0.8 respectively. All of these studies however included substitute prices as explanatory variables and when the impact of these prices is captured in a single own price elasticity, the own price elasticity is expected to be smaller.

Fewer maize specific studies have been conducted in the East African region, but Olwande, Ngigi & Nguyo (2009) evaluated Kenyan maize farmers responsiveness to price and non-price factors, reporting elasticities of 0.11 for maize prices, without accounting for cross price effects explicitly and -0.06 for fertiliser prices. In a much earlier study, Marienga (1996) estimated the dynamic supply response of maize in Kenya and reported a short run elasticity of 0.67 and a long run elasticity of 3.3 on Kenyan maize prices, in this instance the cross price effects were modelled explicitly. Furthermore, a short and long run elasticity of -0.07 and -0.34 respectively was reported with respect to fertiliser prices. The implied coefficient on the lagged area is 0.8.

In light of the various estimations concluded in the region, as well as prior assumptions included in the first version of the ReNAPRI maize model, the assumptions associated with the supply functions in the model is presented in Table 4.4. The simulation model is calibrated over the period 2005 to 2015, based on these elasticity assumptions.

**Table 4.4: Supply elasticity assumptions for the proposed model**

| Country | Lagged area harvested | 3-year weighted average returns | |
|---|---|---|---|
| | | Short run | Long run |
| Kenya | 0.60 | 0.20 | 0.50 |
| Malawi | 0.38 | 0.25 | 0.40 |
| Mozambique | 0.45 | 0.30 | 0.55 |
| South Africa | 0.33 | 0.22 | 0.33 |
| Tanzania | 0.45 | 0.30 | 0.55 |
| Uganda | 0.45 | 0.30 | 0.55 |
| Zambia | 0.55 | 0.40 | 0.89 |
| Zimbabwe (Small-scale) | 0.13 | 0.25 | 0.29 |
| Zimbabwe (Commercial) | 0.11 | 0.35 | 0.39 |

Yield growth and volatility provide an important component of production. In the predominantly rain-fed system employed in SSA, weather related shocks are expected to account for the bulk of yield volatility. Given that the analysis of weather impacts is beyond the scope of this study, yield functions are adopted from ReNAPRI (2013) as a function of technology trends based on historic growth, with a small response to total area and expected returns. In Zambia and Malawi, a shift variable is included for the period during which the input subsidy program was implemented, to account for increased fertiliser use. The theoretical function is presented below:

$$MAZ_{YLD} = \alpha + \beta_1 MAZ_{AH} + \beta_2 MAZ_{RET(avg\ t,t-1,t-2)} + \beta_3 TREND + \beta_4 SHIFT + \mu \quad (12)$$

Where:
$MAZ_{YLD}$ is the maize yield
$MAZ_{AH}$ is the maize area harvested
$MAZ_{RET}$ is Maize returns calculated as area*yield/Input cost index
TREND is a country specific trend variable based on past growth from 2000 to 2014
μ is the residual

The elasticity assumptions for the countries included in the model is presented in Table 4.5. The elasticity associated with the returns variable is adopted from the FAO's COSIMO model. The volatility introduced to the yield equation by changing weather conditions complicates estimation of the economic response, particularly when data quality is also a concern. The impact of returns is expected to be small however given that the use of improved inputs remains limited in many countries and given the small scale of production, fewer changes in input use in response to price expectations are expected. The elasticity is increased in South Africa and the commercial sector in Zimbabwe, where larger producers are expected to show a greater response in management practices when prices change. Having modelled the area decision and trend yield, production is calculated as an identity in each country.

**Table 4.5: Yield equation elasticity assumptions**

| Country | Maize returns | Trend coefficient |
|---|---|---|
| Kenya | 0.05 | 0.015 |
| Malawi | 0.05 | 0.005 |
| Mozambique | 0.05 | 0.001 |
| South Africa | 0.10 | 0.097 |
| Tanzania | 0.05 | 0.041 |
| Uganda | 0.05 | 0.083 |
| Zambia | 0.05 | 0.035 |
| Zimbabwe (Small scale) | 0.05 | 0.0003 |
| Zimbabwe (Commercial) | 0.10 | 0.021 |

### 4.2.2 Domestic demand

On the demand side, the behavioural equations for domestic use are disaggregated into food and feed use. Food use is modeled on a per capita basis, as a function of prices and per capita income levels, before being aggregated to total food use in an identity that multiplies per capita consumption with population numbers. Consumers are assumed to be rational in their behavior, opting to maximize utility subject to a budget constraint. The utility maximization problem is detailed in Meyer (2006), which indicates that consumption is typically estimated as a function of own prices, substitute prices and disposable income. Given that prices for substitute commodities would be exogenous in the proposed single commodity model, consumption is modelled as a simplified function of maize prices and per capita GDP, a popular proxy for disposable income. The theoretical function is presented below:

$$MAZ_{PC} = \alpha + \beta_1 MAZ_{PR} + \beta_2 GDP_{PC} + \mu \qquad (13)$$

Where:

$MAZ_{PC}$ is maize consumption per capita

$MAZ_{PR}$ is the real maize price, deflated using the GDP deflator

$GDP_{PC}$ is the real GDP per capita

μ is the residual

The nature of maize as a basic food staple in the region supports the expectation of an inelastic demand function both in terms of income and price elasticities. The inelastic nature of demand is confirmed by various authors, including Cutts & Hassan (2003) across the SADC region, Meyer (2006) in South Africa, Kapuya (2010) in Zimbabwe and Mapila *et al*. (2013) in Malawi. The own price and income elasticities estimated by the respective authors is presented in Table 4.6.

**Table 4.6: Maize demand elasticities from literature**

| Source | Country | Own price | Income |
|---|---|---|---|
| Cutts & Hassan (2003) | Malawi | -0.06 | 0.08 |
| Cutts & Hassan (2003) | Mozambique | -0.17 | 0.33 |
| Cutts & Hassan (2003) | Tanzania | -0.13 | 0.01 |
| Cutts & Hassan (2003) | South Africa | -0.19 | 0.08 |
| Cutts & Hassan (2003) | Zambia | -0.02 | 0.09 |
| Cutts & Hassan (2003) | Zimbabwe | -0.08 | 0.10 |
| Meyer (2006) | South Africa | -0.16 | -0.14 |
| Kapuya (2010) | Zimbabwe | -0.05 | 0.13 |
| Mapila et al. (2013) | Malawi | -0.23 | 0.47 |

Given the elasticities presented in Table 4.6, as well as the maize food use elasticities contained in ReNAPRI (2013), the assumptions applied in the simulation model are presented in Table 4.7. In some instances, such as Malawi, the income elasticity is adjusted downwards. Absolute income levels rise over time and by Engels law, the elasticity is expected to decline as a result. Furthermore, Malawian maize consumption is already the highest in the region and marginal gains from additional consumption is expected to decline. By contrast, price elasticities were adjusted upward in cases such as Zimbabwe and Zambia, in order to improve the historic fit of the data and ensure theoretical consistency. Since 2003, when the lower estimates of Cutts & Hassan (2003) were generated, food prices globally have risen substantially and low-income consumers, who still spend a significant share of their budget on food products, are expected to be more elastic relative to the lower cost period prior to 2003. Similarly, in countries such as Zimbabwe, where poverty has increased over the past decade, own price elasticities for a basic good such as maize are expected to be larger than those estimated by Kapuya (2010). The adjustments made to own price and income elasticities in the different countries ensure that own price elasticities exceed income elasticities, which is an implied requirement if the homogeneity condition is to be met for maize, which has realistic substitutes.

**Table 4.7: Food demand elasticity assumptions**

| Country | Own price | Income |
|---|---|---|
| Kenya | -0.20 | 0.05 |
| Malawi | -0.28 | 0.07 |
| Mozambique | -0.25 | 0.10 |
| South Africa | -0.15 | 0.05 |
| Tanzania | -0.25 | 0.05 |
| Uganda | -0.20 | 0.10 |
| Zambia | -0.20 | 0.09 |
| Zimbabwe | -0.35 | 0.10 |

With the exception of South Africa, where feed use accounts for a substantial share of total maize consumption, feed use is not currently a big demand factor within the region. Acknowledging that this can change, a rudimentary feed use equation is included in the model, based on maize prices and income levels as an indicator of demand growth for meat products. Unlike food use however, elasticities are not freely available in literature, implying a need for strong assumptions or estimations. Feed use data quality is poor in most countries however, showing little variation from year to year in countries such as Kenya, Malawi, Uganda and Mozambique. Furthermore, the time-series are short, resulting in limited degrees of freedom for individual regressions.

In order to guide the assumptions on feed use elasticities, a combination of individual regressions and panel data methodology was employed. In countries where individual time series are longer and results yield significant parameters, the estimated elasticities from the individual regressions were adopted. The results of the individual regressions are presented in Table 4.8.

**Table 4.8: Individual regression results: Feed use**

| Country | Period | Coefficients | | Adjusted R-Square | F stat |
|---|---|---|---|---|---|
| | | Real PC GDP | Real maize price | | |
| Kenya | 2001-2014 | 18.21** | 0.0001 | 0.75 | 20.05** |
| Malawi | 2004-2014 | 21.05** | -0.0001 | 0.76 | 16.92** |
| Mozambique | 2006-2014 | 32.15** | -0.009# | 0.76 | 13.85** |
| South Africa | 1995-2015 | 142.39** | -0.24# | 0.87 | 66.03** |
| Tanzania | 2000-2014 | 1.88** | -0.0005 | 0.87 | 46.23** |
| Uganda | 2001-2014 | 0.60** | 0.0002# | 0.85 | 36.93** |
| Zambia | 1995-2014 | 123.04** | 0.02 | 0.69 | 22.25** |
| Zimbabwe | 2000-2014 | 301.25** | -0.38** | 0.78 | 25.37** |

***Significant at 5%, *Significant at 10%, # Significant at 30%*

To complement the individual regressions, a panel data approach was also employed, to improve the degrees of freedom. The estimated model controlled for country specific fixed effects and allowed heterogeneity in the slope variables through the application of the Seemingly Unrelated Regression (SUR) methodology first presented by Zellner (1962). Table 4.9 presents the results of the fixed effects SUR weighted regression. The R-square of more than 0.95 implies a good fit, whereas the F-statistic of 927 renders the model as a whole significant. A test for the validity of the fixed effects model rejected the null hypothesis of no cross section specific effects, implying that cross-sectional heterogeneity must be accounted for and confirming the relevance of the fixed effect specification.

**Table 4.9: Feed demand elasticity estimates for all countries**

| Variable | Coefficient | Elasticity (Average 2006 – 2014) |
|---|---|---|
| Real GDP per capita | 9.30** | 1.269 |
| Real Maize Price | -1.02** | -0.131 |

***Significant at 5%*

Given the results of the individual regression, as well as the SUR panel data analysis presented in Table 4.8 and Table 4.9, Table 4.10 presents the feed demand elasticity assumptions with respect to the real maize price and the Real GDP per capita. When significant and in line with prior expectations in terms of economic theory, individual regression results were adopted, with the panel data estimate applied in instances where individual results were not conclusive.

**Table 4.10: Feed demand elasticity assumptions**

| Country | Real maize price | Real PC GDP |
|---|---|---|
| Kenya | -0.13 | 1.27 |
| Malawi | -0.13 | 1.27 |
| Mozambique | -0.30 | 1.27 |
| South Africa | -0.10 | 1.65 |
| Tanzania | -0.28 | 1.53 |
| Uganda | -0.20 | 1.50 |
| Zambia | -0.17 | 1.24 |
| Zimbabwe | -0.60 | 1.50 |

The last component of the demand block relates to stock levels, which are modelled as a function of beginning stocks, production levels and maize prices - implying that a rise in prices would cause stocks to be released. In many countries, stocks are managed by government as a strategic grain reserve and in such instances, the relevant policies are included in the stock equations as a minimum stock level to be maintained. These minimum levels relate to typical stock to use ratios maintained since 2005 and differ across countries.

A few studies have modelled maize stocks in the ESA region, providing a guideline for elasticity estimates. Meyer (2006) in South Africa, Kapuya (2010) in Zimbabwe and Mapila *et al.* (2013) in Malawi all based the stock equation on the same explanatory variables, in line with ReNAPRI (2013). The theoretical equation is presented below:

$$MAZ_{ES} = \alpha + \beta_1 MAZ_{ES(-1)} + \beta_2 MAZ_{PROD} + \beta_3 MAZ_{PR} + \mu \tag{14}$$

Where:

$MAZ_{ES}$ is the maize ending stock in the current period

$MAZ_{ES(-1)}$ is the maize beginning stock in the current period

$MAZ_{PROD}$ is the maize production in the current period

$MAZ_{PR}$ is the real maize price in the current period

μ is the residual

Elasticities in the literature highlight a fair amount of variation across countries. The beginning stock variable ranges from 0.24 for yellow maize in South Africa (Meyer, 2006) to 0.64 in Zimbabwe (Kapuya, 2010). Likewise the own price elasticity ranges from -0.04 (Kapuya, 2010) to -1.05 (Meyer, 2006) and the elasticity of stock levels to production from 0.02 (Kapuya, 2010) to 2.15 (Meyer, 2006). Given the lack of literature related to stock estimation in countries other than South Africa, Zimbabwe and Malawi, combined with the poor data quality, assumptions are imposed in line with literature on similar countries, analyst judgement and economic theory. These assumptions are presented in Table 4.11.

**Table 4.11: Ending stock elasticity assumptions**

| Country | Beginning stocks | Own price | | Production | |
|---|---|---|---|---|---|
| | | Short term | Long term | Short term | Long term |
| Kenya | 0.45 | -0.80 | -1.45 | 0.65 | 1.18 |
| Malawi | 0.45 | -0.80 | -1.67 | 0.65 | 1.36 |
| Mozambique | 0.45 | -0.80 | -1.53 | 0.65 | 1.24 |
| South Africa | 0.24 | -0.85 | -1.10 | 0.90 | 1.16 |
| Tanzania | 0.45 | -0.80 | -1.45 | 0.65 | 1.18 |
| Uganda | 0.45 | -0.80 | -1.48 | 0.65 | 1.20 |
| Zambia | 0.45 | -0.80 | -1.48 | 0.65 | 1.20 |
| Zimbabwe | 0.55 | -0.60 | -1.44 | 0.50 | 1.20 |

## 4.3 Model validation

The need to validate simulation models used for policy analysis has been a long standing topic best described by Kleijen (1999) as 'deciding whether the simulation model is an acceptable representation of a real system given the purpose of the simulation model'. In discussing validation of an improved model structure within the South African agricultural sector, Meyer (2006) suggested that hypotheses can be specified to test the validity of individual parameters contained in the model, yet in light of the sheer number of parameters included in multi-market models, questions the practicality and usefulness of such an exercise. He also notes that even when models perform well statistically, this does not guarantee its ability to handle real world scenarios satisfactorily. Furthermore, data limitations and identification issues has popularized the use of synthetic parameters (Van Tongeren *et al.*, 2001), which cannot be validated statistically (Meyer, 2006; Gass, 1983).

Consequently, the ability to generate reliable and plausible estimates of real world scenarios have been offered as a form of model validation, with plausibility simply evaluated against prior expectations of industry experts and consistency with economic theory (Meyer, 2006; Nolte, 2006). Kleijen (1999) indicates that this provides a very important technique in the absence of actual data that can be used to verify simulation results and failure of a model to generate output that is consistent with qualitative prior expectations should seriously question its validity.

Gass (1983) first proposed that subjection of a model to invalidation tests can raise confidence in its credibility, pointing to the notion of replicative validity which entails evaluation of how closely data from a simulation model matches reality through analysis of errors between predicted and real outcomes historically. This methodology has been employed by a number of authors, with validation experiments typically consisting of simulations over a historic period, particularly whilst controlling for external factors that the model cannot be expected to anticipate, such as policy reforms or weather related yield volatility (Van Dijk, Philippidis & Woltjer, 2016; Liu, Arndt & Hertel, 2004; Gehlhar, 1997; Kehoe, Polo & Sancho, 1995). The availability of real output for comparative purposes enables the use of statistical validation tests, provided enough observations can be generated (Kleijen, 1999).

Whilst it may not be possible to validate projections generated by a simulation model due to the absence of actual data, different model structures have been compared, noting both the ability to reduce error in historic simulations and plausibility in generating projections for different scenarios as a measure of improved performance (Dillen & Gay, 2014; Nolte, 2006). Kleijen (1999) further indicates that sensitivity, or 'what if' analysis can be used for qualitative validation.

In evaluating the performance of the bilateral trade modeling structure in relation to the traditional price linkage approach, three sets of criteria are adopted. Firstly, after accounting for production fluctuations, historic simulations are conducted for 2013 - 2016 with the bilateral trade model, as well as the traditional price linkage model, comparing estimation errors in projecting prices (Van Dijk *et al.*, 2016; Dixon & Rimmer, 2010). This represents a short but volatile simulation period.

Secondly, as suggested by Kleijen (1999), simple sensitivity analysis related to individual variable changes and multiple simultaneous changes will be conducted to evaluate the bilateral trade model's ability to capture shocks to exogenous or endogenous variables, evaluating the results for economic consistency in direction of movement. A baseline outlook will be generated with both models and evaluated for plausibility, after which simple shocks to world prices and domestic production levels are applied. Furthermore, historic yield and world price volatility will be replicated over the 10-year projection horizon. The different models are evaluated for plausibility, consistency with economic theory and their ability to replicate historic price volatility as validation technique (Van Dijk *et al.*, 2016).

Thirdly, in the spirit of Boland (1989), who argued that, being an approximation of the real world as opposed to an exact replication, a model must ultimately be judged on the degree to which it provides credible answers to the questions that it was designed to address, the model will be applied to two different policy related questions in order to illustrate its usefulness and application to real world problems. These policy simulations will be described in Chapter 5.

### 4.3.1 Historic simulation

To compare predictive power over historic data, a traditional price linkage equation, as well as the proposed trade-linked model are both calibrated over the period 2005-2015 using the elasticities provided in Section 4.2. Both models are then simulated to generate maize prices for 2013 to 2016 in each of the 8 countries. These simulated prices are compared to actual historic values for this period and evaluated for goodness of fit. The same calibration technique was used for both models to ensure consistency and error terms for 2013 to 2016 were fixed at 2012 values for domestic market behavioural equations. The price linkage equation used for comparative purposes assumes a transmission elasticity of 0.9 from the global market.

Different measures have been proposed in literature to evaluate the predictive power of simulation models used over an historic period. Van Dijk *et al.* (2016) notes that conventional measures such as the coefficient of determination ($R^2$), root mean square error (RSME) and Pearson's correlation coefficient are still regularly used for model validation. It has been argued however that they are poor measures of model performance due to their oversensitivity to extreme values and insensitivity to additive and proportional differences between simulated and observed values (Legates and McCabe, 1999; Willmott *et al.*, 1985). For this reason, a number of additional measures have been developed, which have been commonly used in model validation exercises (Van Dijk *et al.,* 2016). Three of these measures, the mean absolute error (MAE), the modified index of agreement (MD) and the modified Nash-Sutcliffe efficiency (mNSE) are complemented by the traditional RMSE to compare the predictive power of the traditional price linkage model to that of the proposed trade-linkage model.

The MAE is the average absolute difference between the simulated (S) and observed (O) value for each observation *i* and can be presented as:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|S_i - O_i| \qquad (15)$$

The MAE is a dimensional measure that ranges from zero to infinity and can therefore not easily be applied to compare different models and datasets. In this instance it is applicable because the comparison relates to two different models calibrated over the same dataset and simulating the same data. It is however also complemented by two additional non-dimensional measures. The first is the MD, developed by Wilmott *et al.* (1985) and defined as:

$$MD = 1 - \frac{\sum_{i=1}^{N}|S_i - O_i|}{\sum_{i=1}^{N}(|S_i - \bar{O}| + |O_i - \bar{O}|)} \qquad (16)$$

Van Dijk *et al.* (2016) indicates that the denominator is a measure of the "potential error" which represents the largest possible value that $|S_i - O_i|$ can reach for each simulation-observation pair. Consequently, the MD is always between 0 and 1, with larger values indicative of improved correlation between simulations and actual observations. Lastly the mNSE, sometimes also referred to as the coefficient of modelling efficiency was developed by Legates and McCabe (1999), based on work by Nash and Sutcliffe (1970). It can be represented as follows:

$$nNSE = 1 - \frac{\sum_{i=1}^{N}|S_i - O_i|}{\sum_{i=1}^{N}|O_i - \bar{O}|} \qquad (17)$$

The mNSE ranges from minus infinity to 1, with higher numbers again corresponding to improved fit. It provides the added advantage of comparing model simulations to the observed mean as a predictor and any positive value indicates that the model is an improvement on the mean observed value. Results for the different indicators are presented in Table 4.12.

**Table 4.12: Selected validation statistics for model comparison**

| Measure | Traditional price linkage equation | Proposed trade-linked model |
|---|---|---|
| Root Mean Square Error (RMSE) | 26.87% | 18.72% |
| Mean Absolute Error (MAE) | 21.53% | 13.42% |
| Modified Index of Agreement (MD) | 0.47 | 0.61 |
| Modified Nash Sutcliffe Efficiency (nMSE) | -0.09 | 0.32 |

Across all four indicators, the trade-linked model outperformed the traditional price linkage approach by a significant margin, reflecting a lower RMSE and MAE accompanied by a higher MD and nMSE. This is in line with prior expectation given that the last two years in question represented below average yields in the ESA region, accompanied by well stocked global markets. In this situation, the traditional price linkage approach would not be expected to perform well. Supporting the validity of the model, the MD of 0.61 for the trade model is closer to 1 (good fit) than 0 (poor fit) and also compares well to the MD of 0.59 found to be acceptable when validating a global CGE model by Van Dijk *et al.* (2016). Similarly, the nMSE of 0.32 compares well to the 0.26 found acceptable by Van Dijk *et al*. (2016). In light of differences in period, country inclusion and product coverage, the model presented here is not compared to that presented by Van Dijk *et al.* (2016), however the numbers considered acceptable in their study provide some guidance on the performance and hence validity of the model presented.

### 4.3.2 Simulation of 10-year outlook: Baseline

Given the objective of forward looking policy simulations, the historic performance of the model must also be complemented by an ability to generate a plausible future outlook. The plausibility of such an outlook is however subjective in nature and can only be compared to specialist judgement and analyst review. The same procedure is followed however, generating a 10-year price projection for maize prices across the region using both the traditional price linkage and proposed trade linkage approach.

The baseline presents a single possible future scenario based on a plausible set of macro-economic assumptions which does not account for volatile weather conditions. As a result, prices lack volatility over the outlook period, instead representing an equilibrium given the underlying fundamentals of supply and demand dynamics. The world price is exogenous to the regional model and is provided by FAPRI (2016).

Figure 4.1 indicates that the price-linkage model provides a similar outlook to that of the world price, which is true by design. Globally, the outlook is underpinned by an implied slowdown in global maize consumption following a slowdown in Chinese economic growth and a stagnant biofuel sector. Similar to this global picture, regional prices move largely sideways in US dollar terms, increasing only as a result of transportation cost changes. Prices remain at a level below recent peaks, but above historic, pre-2007 norms. The price equation has a small self-sufficiency impact to incorporate some domestic supply and demand dynamics in the price, but price movements resulting from this remain small. By implication, a drought scenario will have a very limited impact on prices, merely resulting in increased trade volumes.

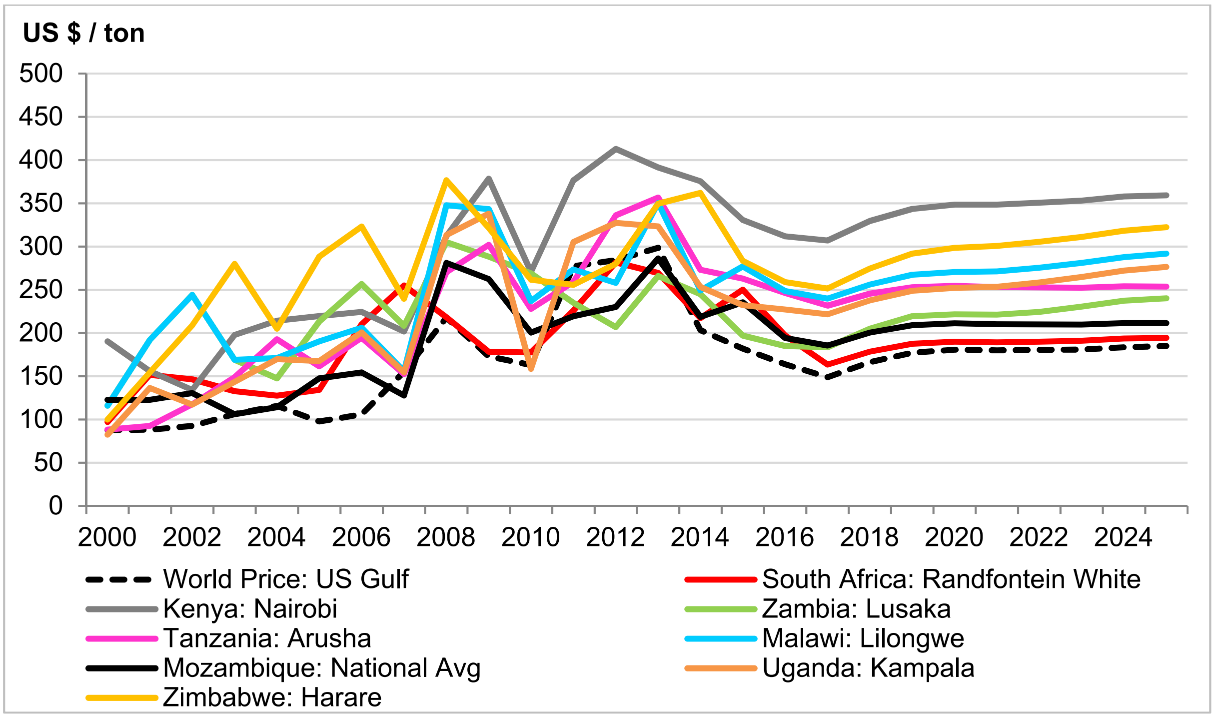

**Figure 4.1: Baseline price projection simulated with price linkage approach**

By contrast Figure 4.2 presents rising prices in the region, underpinned by growing consumption due to continued growth in per capita income and rapidly expanding populations. This results in growing consumption as food, as well as the emergence of feed use as the demand for meat products grow. Particularly in countries where the supply response is slower, such as Kenya and Zimbabwe, prices increase over time.

A more elastic demand specification would result in less of an increase in prices. Prices generally move further away from each other over time, as transportation rates increase in line with inflation and oil price movements. In a drought situation, prices would respond to the domestic shortage, reducing consumption and stock levels as the system responds. Therefore, the trade impact from outside the region would be smaller than in a direct price linkage approach. The difference in the required response in clearly illustrated in South Africa, where prices moved away from the world reference in the drought influenced 2015 and 2016 seasons, but return to global levels over the projection period under the assumption of a return to normal weather. Therefore, prices are able to move to import parity levels under a domestic shortage, but fall back to export parity levels in a surplus situation.

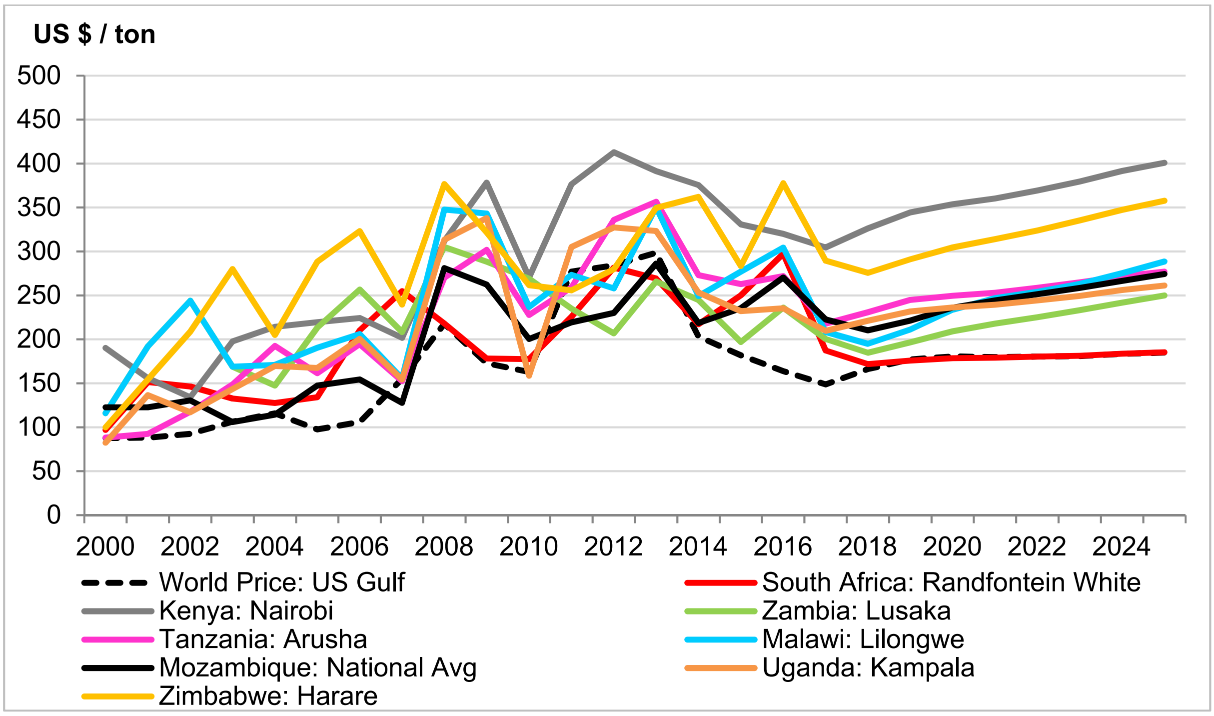

**Figure 4.2: Baseline price projection simulated with trade linkage approach**

The key difference in the projections generated by the two models rests in the trade values. The price linkage model is based on the assumption that maize is homogeneous in the global market and trade-flow is infinitely elastic, hence lower prices result in less production and stronger consumption. In countries such as Kenya, Mozambique and Zimbabwe, net imports increase significantly relative to the higher price outlook generated by the trade linkage model (Figure 4.3). This difference is substantial and in the outlook generated by the price linkage model, the aggregate region trades much closer to self-sufficiency by 2025, as opposed to remaining a stronger net exporter under the outlook generated by the trade linked model. Given that South Africa continues to switch to yellow maize that is typically exported outside of the region, the higher exports seem more likely.

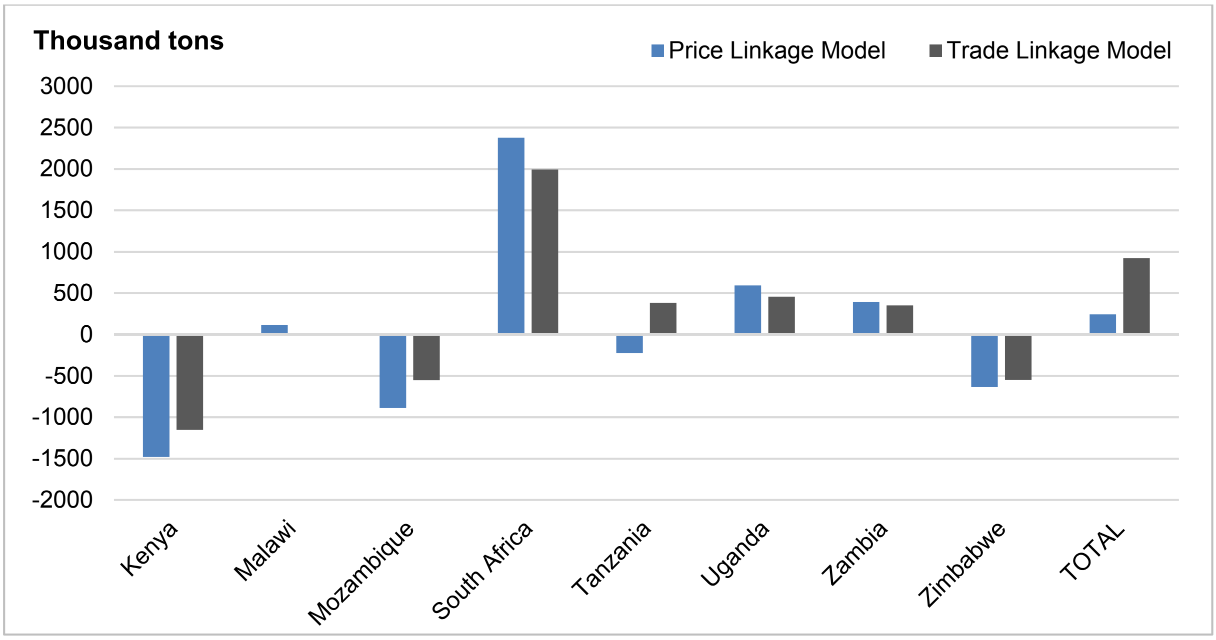

**Figure 4.3: Baseline projection: Net trade by country in 2025**

Both models seem to generate a plausible future outcome and analyst judgement related to the likelihood of each scenario materializing is highly subjective. Traditional South African yellow maize export volumes into the global market implies that the lower net trade projection generated by the price linkage model would require rising imports from the global market into the rest of the region. Historically, trade has occurred mostly within the region rather than in the global market, given that non-GM white maize is differentiated from maize typically traded in the global market. Hence rising prices which support increased production and trade dominated by intra-regional movements seems more plausible given historic trends. Furthermore, well documented high costs and logistical challenges related to transportation suggests that trade would be well below infinitely elastic.

The subjective nature of “plausibility” implies that the baseline projection is not the ultimate measure of model performance. Instead, it merely represents the starting point, with the difference in response to simple domestic and global market shocks a better measure of relative model performance.

### 4.3.3 Sensitivity to global and domestic markets shocks

In order to evaluate the response of the two different modelling structures to changes within and outside of the region, two simple scenarios are introduced. The first is a 10% increase in the world reference price for maize in 2018, returning to baseline levels from 2019 onwards. The second is a 10% decline in domestic production levels across the region in 2018. The shock is not introduced beyond 2018, but allowed to dissipate over time, hence production levels post 2018 are also affected, but as a response to price changes and not a result of exogenous factors.

Table 4.13 presents the results of the first scenario related to a global market shock. It illustrates the percentage change in prices for each country included in the model relative to the baseline presented in Section 4.3.2. In the trade linkage approach, the impact of the world price shock is significantly lower than in the price linkage model. This results from global prices being transmitted to domestic markets through trade instead of direct price linkages. Results are consistent with literature noting the isolation of maize markets in the region from global markets (Baffes *et al.,* 2015; Baquedano & Liefert, 2014; Minot, 2011). The highest rate of price transmission from the world in the trade linked model is evident in South Africa, which is consistent with historic trade and prior expectation as South Africa trades yellow maize in the global market.

**Table 4.13: Scenario 1: 10% increase in the world reference price in 2018 - Percentage change in prices relative to the baseline**

| **Country** | **Trade linkage model** | | **Price linkage model** | |
|---|---|---|---|---|
| | **2018** | **2019** | **2018** | **2019** |
| Kenya | 1.80% | -0.22% | 5.21% | 0.00% |
| Malawi | 0.40% | -0.12% | 4.28% | 0.00% |
| Mozambique | 3.44% | -0.50% | 6.76% | 0.00% |
| South Africa | 5.85% | -0.54% | 7.01% | -0.09% |
| Tanzania | 1.07% | -0.38% | 5.91% | 0.00% |
| Uganda | 1.71% | -0.44% | 4.19% | 0.00% |
| Zambia | 0.59% | -0.19% | 5.48% | 0.00% |
| Zimbabwe | 0.48% | -0.13% | 4.96% | 0.00% |
| World Price: US Gulf | 10.00% | 0.00% | 10.00% | 0.00% |

Table 4.14 presents the results of the second scenario where domestic supply in each of the eight modelled countries is reduced by 10% in 2018. It highlights the percentage change in prices in the relevant countries relative to the baseline presented in Section 4.3.2. Within the price linked approach, where domestic prices are simply a function of international price movements, the domestic yield shock has no impact on price levels within the relevant countries, as infinitely elastic trade flow simply increases to fill the deficit in domestic supply. Given the consensus in literature that domestic supply and demand factors have a greater impact on price volatility in the region than world prices, this seems unrealistic.

**Table 4.14: Scenario 2: 10% decline in domestic supply in 2018 - percentage change in prices relative to the baseline**

| **Country** | **Trade linkage model** | | **Price linkage model** | |
|---|---|---|---|---|
| | **2018** | **2019** | **2018** | **2019** |
| Kenya | 7.91% | 0.13% | 0.00% | 0.00% |
| Malawi | 23.92% | -1.76% | 0.00% | 0.00% |
| Mozambique | 15.78% | 1.58% | 0.00% | 0.00% |
| South Africa | 15.18% | 1.99% | 0.00% | 0.00% |
| Tanzania | 20.83% | -0.83% | 0.00% | 0.00% |
| Uganda | 19.49% | 0.52% | 0.00% | 0.00% |
| Zambia | 24.15% | 0.48% | 0.00% | 0.00% |
| Zimbabwe | 15.13% | 0.36% | 0.00% | 0.00% |
| World Price: US Gulf | 0.00% | 0.00% | 0.00% | 0.00% |

Within the trade linked model, domestic price movements exceed the supply shock in all markets except Kenya, which is a consistent net importer which typically trades at import parity and is also able to import from outside of the region into Mombasa. Price movements exceeding the domestic supply shock is in line with inelastic demand of a basic food staple. Price movements are the largest in landlocked countries such as Malawi and Zambia.

### 4.3.4 Simulation of 10-year outlook: Volatility

Agricultural markets are notoriously volatile given the biological cycle of production and dependence on changeable weather conditions. Whilst a baseline projection has the role of providing a benchmark for policy analysis, it does not account for this volatility. When yield or world price volatility is introduced exogenously into the model however, its validity, and usefulness for a range of scenarios, can also be measured by its ability to replicate historic price volatility. The introduction of volatility into simulation models is often achieved through stochastic simulation (Van Dijk *et al.,* 2016), where error terms for functions such as yields are drawn from a distribution. It can however also be introduced by replicating the yield and / or world price volatility associated with an historic period in the projection, which also allows comparison of price volatility over the historic period and the projection.

For the purpose of model comparison, historic volatility over the period 2009-2016 in both country level yield functions and world price projections is carried forward to the projection period. Figure 4.4 presents the results of the price linkage model and indicates that, by design, regional prices follow a similar pattern to the world price. Relative price levels in the region do not change significantly over the outlook relative to the last year of actual data (2015), despite significant differences in yield shocks between Southern and Eastern Africa in particular. This structure assumes that maize is a homogeneous good traded into a single pooled market, resulting in trade fluctuations as a result of domestic yield volatility rather than price movements within each market.

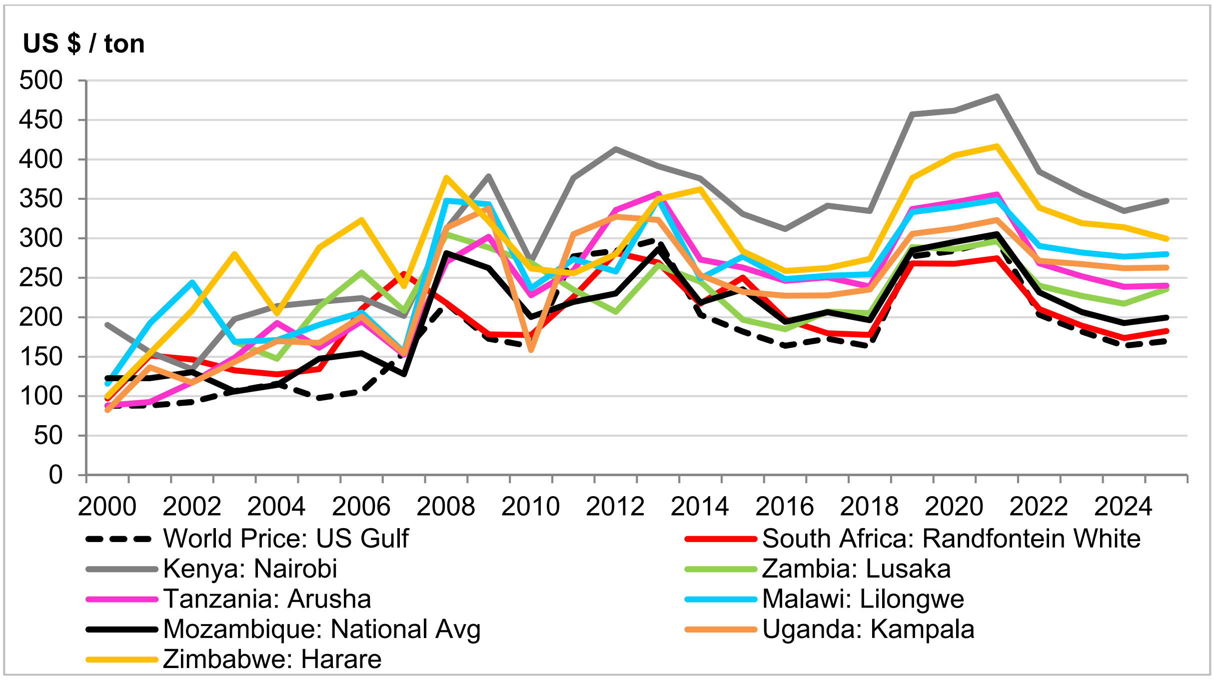

**Figure 4.4: Volatility scenario simulated with price linkage approach**

As an alternative to the model that assumes a homogeneous good in the global market, the South African white maize price can be used as a regional reference price instead. In this instance, South African prices are derived from domestic supply and demand conditions, with other prices in the region linked to the South African price instead. Figure 4.5 indicates that this introduces more deviation from the world price, making it more consistent with historical trends. Nonetheless regional prices still respond only to production shocks in the South African market and if for instance weaker yields in the Eastern African region is accompanied by good yields in the Southern African region (as in 2009 and replicated in 2017), prices do not deviate.

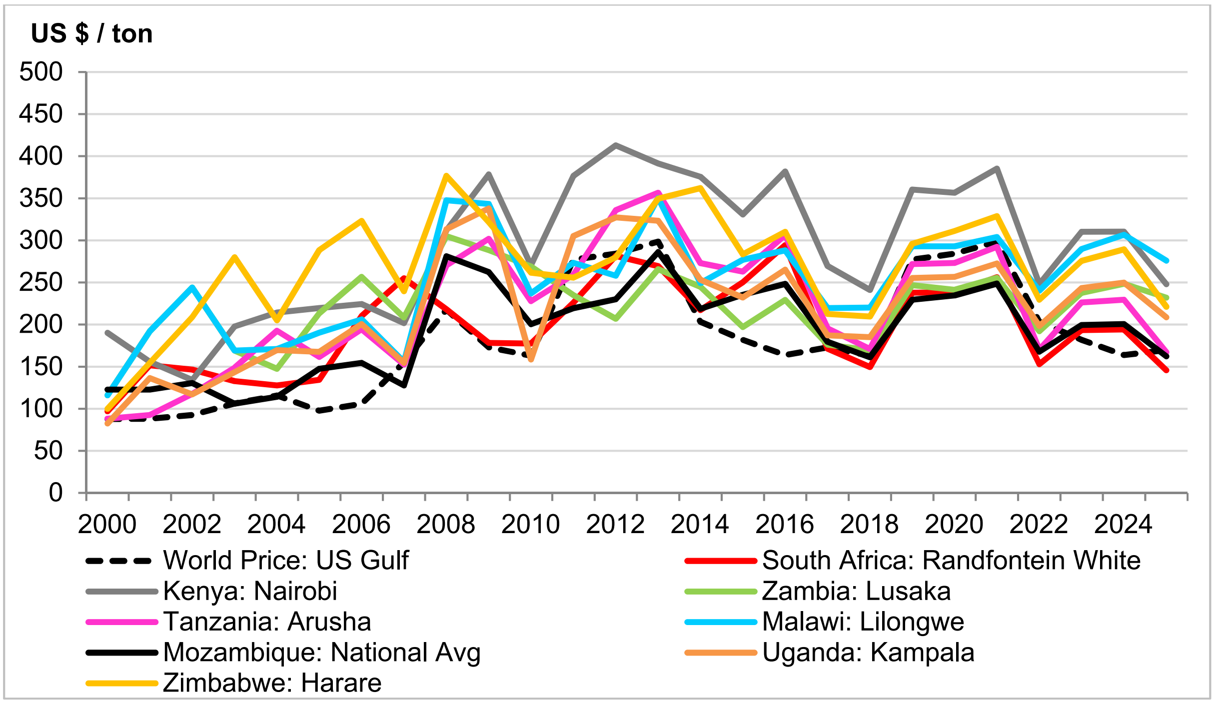

**Figure 4.5: Volatility scenario simulated with price linkage approach using South Africa as a reference price**

Figure 4.6 highlights the benefit of the trade linkage approach in capturing the combination of domestic supply and demand dynamics in each country, whilst linking regional markets through bilateral trade. When historic volatility is introduced, prices react accordingly in the projection period. As an example, the 2009 scenario replicated in 2017 shows Kenyan prices increasing whilst South African and Zambian prices decline. In other periods however, such as 2019 and 2020, these prices move together.

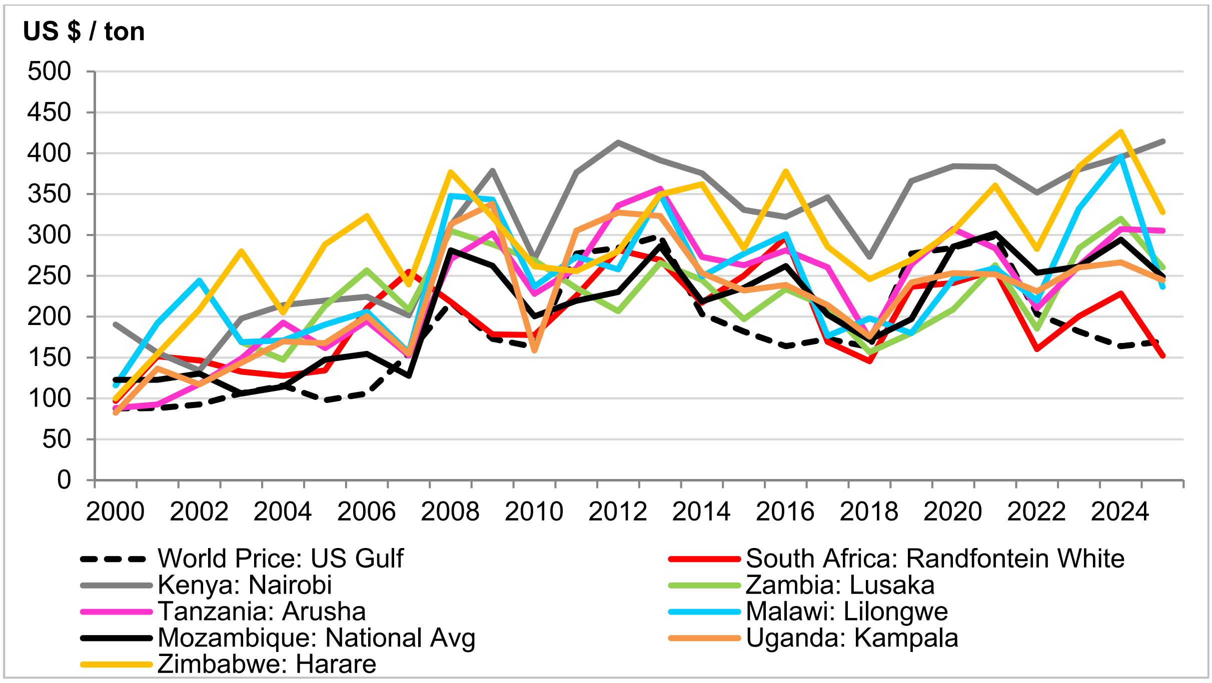

**Figure 4.6: Volatility scenario simulated with trade linkage approach**

As a measure of the extent to which the different modelling approaches were able to replicate historic price volatility, Table 4.15 shows the coefficient of variation as measure of volatility in real prices in each market in the historic (2009-2016) period, as well as the 2017 to 2025 projection. Domestic yield shocks, combined with world price volatility would be expected to account for the largest share, but not entirely all of the volatility evident in these markets. Hence volatility associated with the projection period is expected to remain below that of the historic period.

**Table 4.15: Coefficient of variation in real prices for three different approaches**

| Country & market | 2009-2016 | 2017-2025 | | |
|---|---|---|---|---|
| | Historic | Price linkage | Price linkage (SA World price) | Trade linkage |
| South Africa: Yellow | 22.70% | 22.88% | 23.64% | 22.31% |
| South Africa: White | 29.74% | 23.79% | 25.38% | 24.19% |
| Zambia: Lusaka | 20.49% | 16.13% | 13.11% | 19.46% |
| Tanzania: Arusha | 12.16% | 18.97% | 22.67% | 16.24% |
| Mozambique: Nat Avg. | 27.71% | 21.06% | 17.64% | 16.88% |
| Zimbabwe: Harare | 15.09% | 17.21% | 17.59% | 14.99% |
| Uganda: Kampala | 23.19% | 12.97% | 14.50% | 9.18% |
| Malawi: Lilongwe | 36.06% | 13.64% | 11.29% | 24.88% |
| Kenya: Nairobi | 14.93% | 18.19% | 19.86% | 8.22% |
| World (US Gulf) | 26.79% | 26.79% | 26.79% | 26.79% |

When prices are linked to a world reference price, domestic supply and demand responses to price changes have very little impact on price movements, resulting in an over-estimation of historic volatility in some cases. By contrast, the combination of reactions on both the supply response and consumption levels emanating from the changing prices allow for volatility to be replicated more efficiently in the trade linkage approach. In most markets, projected volatility is marginally less relative to the historic period, with Tanzania proving the exception. Tanzania has a history of intervention in order to manage volatility, which is not modelled in the projection period, hence increased volatility may be expected. This increase in volatility in Tanzania is less in the trade-linkage approach relative to the direct price linkage to the world price.

In typically volatile, landlocked markets such as Malawi and Zambia, the trade linkage model gets much closer to historic volatility than is the case with the price linkage models. On average across the different markets, the absolute deviation (MAE) from the historic volatility is the smallest using the trade-linkage approach. Graphically, the trade linkage model also yields price volatility that more closely resembles historic figures than is the case with the price linkage models.

### 4.4 Concluding Remarks

This chapter presented the model specification and applied a number of techniques to validate the proposed trade-linkage model. In most instances, the model specification relied on synthetic calibration as opposed to econometric estimation, due to limited observations, poor quality of historic data and the rapidly changing agricultural environment evident in the region over the past decade.

Given that no single statistical measure can be applied to validate a synthetically calibrated simulation model, different techniques were applied to compare the proposed trade linkage model to a more traditional price linkage approach. The trade linkage model performed more accurate simulations historically and also generated a more plausible outlook over a ten-year horizon. Lastly, it was more efficient in replicated historic price volatility when historic supply fluctuations and world price volatility were replicated over a future period. Price movements were consistent with economic theory related to supply and demand dynamics.

Combined the three different approaches served to validate the consistency and efficiency of the trade linkage model, suggesting that it is a more accurate representation of reality than previous price linkage approaches. Having validated the structure, which has the added benefit of allowing for trade-control scenarios to be simulated explicitly, the model will be applied to simulate different policy related scenarios in Chapter 5. This will also serve as a last form of validation in illustrating the model structures usefulness in simulating real world scenarios.

# 5. MODEL APPLICATION TO FORWARD LOOKING SCENARIO SIMULATIONS

## 5.1 Introduction

The model presented in Chapter 4 provides a unique structure. This enables it to simulate numerous scenarios that would not have been handled credibly in a traditional price linkage approach due to the implied lack of price impact from domestic supply shocks. This chapter highlights two such instances, both in terms of a short-term response to supply shortages and a longer term strategic view on productivity growth. In the spirit of Boland (1989), who suggests that models should ultimately be judged on their ability to provide credible answers to the questions that they were designed to address, it provides a final validation for the modeling framework described in Chapter 4.

In line with the objectives stated in the Malabo declaration, which includes increased intra-regional trade, as well as a doubling of agricultural productivity across the region, the model is applied to simulate alternative future outcomes in two different contexts. The first relates to the short-term implementation of discretionary trade policies in response to short term fluctuations in supply, where it is able to provide the price, as well as alternative trade-flow implications of implementing export controls. The second relates to the impact of longer term productivity gains on prices and trade-flow across ESA, as well as the prospects for trade initiation if transportation costs can be reduced. Thus, in addition to a final model validation through application to relevant issues affecting the agricultural sector in the region, it also provides guidance to policy makers in quantifying *ex ante* the market impacts of specified policy outcomes. These impacts are evaluated in a regional rather than country specific context and are therefore able to guide policy makers towards the ultimate objective in the Malabo declaration of regional cooperation to eradicate hunger in Africa by 2025.

## 5.1 Short term application: Discretionary export controls to reduce domestic prices

The dramatic increase in world food prices in 2007 brought to the forefront a number of policies intended to stabilise domestic markets and protect consumers (Abbott, 2012). In many exporting countries, export restrictions were applied through the imposition of taxes, quotas or even outright export bans. Africa was no exception and particularly in maize markets, which have a strong connotation with food security, a number of countries resorted to export bans in recent years in an attempt to secure domestic supply and keep prices at tolerable levels. African policy makers are often faced with the need to balance such short-term food security objectives with the longer-term goal of raising productivity growth.

Export restrictions are generally aimed at achieving short run objectives. They tend to be motivated by food security, but at times they also carry political connotations (Mitra & Josling, 2009). This may explain their continued application, despite a body of literature noting the adverse impact on investment and consequently long term productivity gains (Jayne, 2012; Chapoto & Jayne, 2009; Dorosh *et al*., 2009; Jayne & Tschirley 2009). The nature of rain-fed agricultural production, which dominates in the ESA region, results in fluctuating production levels. Intra-regional trade has the ability to reduce the resultant price volatility (Haggblade *et al*., 2008), while a closed border policy can easily lead to price variations in the range of 100% from year to year. Chapoto and Jayne (2009) further note that contrary to price stabilization objectives, prices in Africa tend to be more volatile in markets where governments intervene most actively. While export bans continue to be implemented, the expected gains are often not realised in practice (Mitra & Josling, 2009).

Within Southern Africa, Zambia has been particularly prone to imposing export controls during periods of high prices (Figure 5.1). This has been achieved mainly through outright bans on exports, often imposed in a highly discretionary manner. Government positions on private sector trade often changed at short notice, due to a lack of trust in the private sector and market based factors (Jayne, 2012; Chapoto & Jayne, 2009; Dorosh *et al.,* 2009). Its emergence as a fairly consistent surplus producer in the region in recent years implies that, in addition to the domestic impacts, the implementation of such policies in Zambia has the potential for far-ranging effects across the region. It was noted in Chapter 2 that price transmission patterns in the region differs during periods of open trade as opposed to periods of export controls, implying that policy changes in Zambia will also affect prices in surrounding countries such as Zimbabwe, South Africa, Malawi and Mozambique.

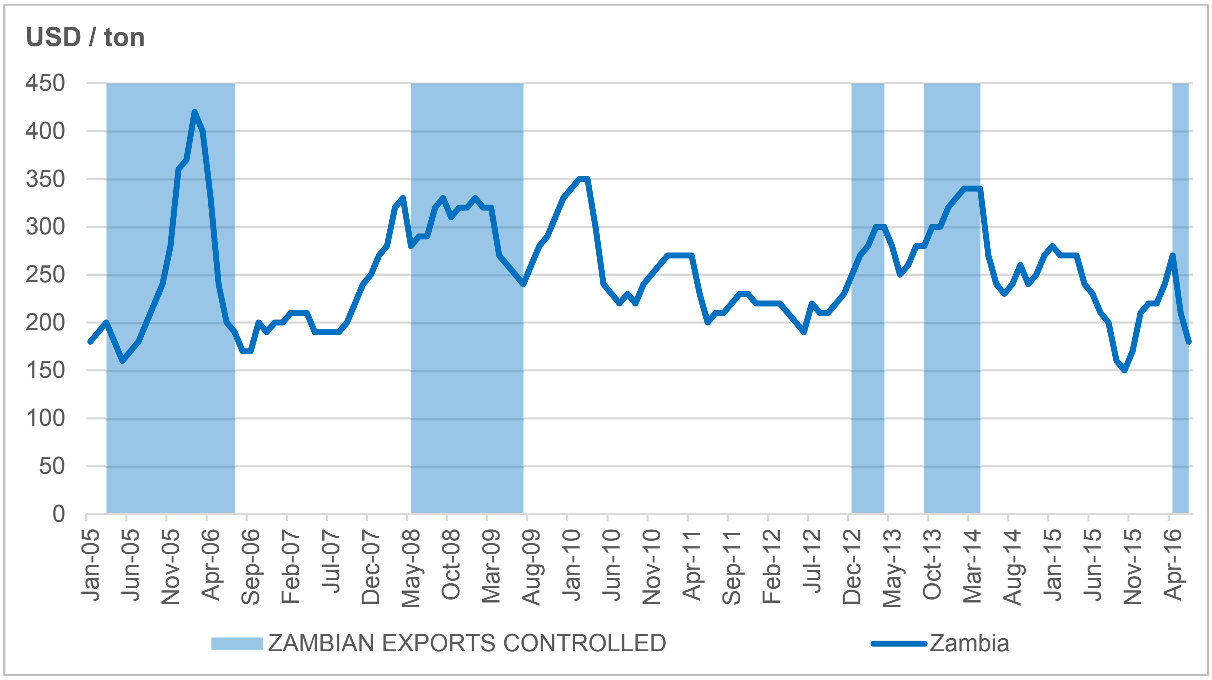

**Figure 5.1: Zambian export controls and prices**
*Source: Compiled from Porteous (2012) & FAO GIEWS (2017)*

### 5.1.1 Implications of export bans

Quantification of the impacts of export controls entails two aspects, the in-country effects where they are applied, which are effectively the target of the policy action, as well as the spillover effects on the rest of the world (Abbot, 2012; Bouet and Laborde, 2010; Mitra and Josling, 2009). Due to the absence of world price effects from export controls imposed in a small country, the bulk of the analysis conducted in the global context has focused on export controls imposed in large countries that export substantial volumes. A greater focus has been awarded to export taxes, rather than outright bans or embargoes, possibly due to their more frequent use by large exporters. The detrimental impacts of outright export bans have however been shown to be larger than that of export taxes or quotas (Mitra & Josling, 2009).

Significant focus in literature remains on the reasons for imposing export bans and while the implications have been explored, it has often been in a qualitative context. Theoretical impacts have been illustrated in a partial equilibrium context by Abbot (2012) as well as Mitra and Josling (2009), while Bouet and Laborde (2010) provide both a partial equilibrium and general equilibrium view on export taxes. The analysis highlights important implications, such as the net welfare loss globally that results from export controls in the short and long term (Bouet & Laborde, 2010; Mitra & Josling, 2009), the increase in global price volatility when large exporters limit exports, which can also offset the domestic price stabilization impact (Martin & Anderson, 2012) and a critical asymmetry between exporters and importers in a food crisis situation. Whereas net exporters can benefit from increased world prices, net importers are hurt and have no capacity to retaliate efficiently (Bouet and Laborde, 2010).

Within the African context, most countries are not considered large enough to move global markets and research related to export bans has tended to focus on the impact in the country where they are applied, mainly in Zambia, prior to its emergence as a consistent surplus producer (Chapoto & Jayne, 2009; Dorosh *et al*., 2009) and Tanzania (Makombe & Kropp, 2016; Baffes *et al.*, 2015). All four of these studies report negative implications. No evidence of price stabilization effects from export bans is established in Zambia (Chapoto and Jayne, 2009), but several studies point to substantial domestic price declines. Using a simple economic model, Dorosch *et al*. (2009) illustrate the impact of production shocks in Zambia under various policy regimes and found that a 30% increase in production from long term average levels halves the price of maize when exports are banned completely, with a smaller but still negative impact associated with various levels of export quotas. In Tanzania, Makombe and Kropp (2016) used a household survey approach to evaluate welfare impacts, whilst Diao *and Kennedy* (2016) used a CGE model. Both highlight reduced prices, lower profits or even losses and consequently a reduction in investment, with maize cultivation reduced in favour of other crops. Thus, production growth stalls as a result of the bans, while private sector investment is reduced.

Only two studies attempt to consider the wider regional impacts of such export bans (Dabalen & Paul, 2014; Porteous, 2012). Findings are less consistent than the studies with a single country focus and somewhat in contrast to theoretical expectations.

Porteous (2012) finds no significant effect on price differences between countries as a result of export bans and highlights an equivalent price increase in both origin and destination country. By contrast, Dabalen and Paul (2014) find a significant decline in Tanzanian prices when export bans are imposed, but with a similar decline evident in Kenya, which represents the usual destination of Tanzanian exports. Alternative import destinations such as Uganda are however not considered and the authors acknowledge that their estimates may fail to isolate the true effects of export bans in the presence of other factors associated with market prices.

Despite the somewhat ambiguous results related to actual price impacts from export bans, theory suggests that they induce a redistribution of welfare from producers to consumers. The global impact is clearly negative when export bans are applied in large countries, but in the absence of a market failure, such interventions still lead to an aggregate welfare loss, even domestically when applied in a small country (Mitra & Josling, 2009). The extent of such welfare loss depends on the relative price elasticities of supply and demand, which suggests that application in basic food staple markets such as maize would result in a bigger welfare loss. As export bans increase availability to domestic consumers, prices decrease in order to absorb additional availability, leading to a price distortion, which is greater when demand is more inelastic.

Figure 5.2 illustrates theoretically the short term domestic impact of applying an export ban in a small exporting country. Initial equilibrium is illustrated by point $E_0$ the point where the country's short run, perfectly inelastic supply curve ($S_s$) intersects global demand ($D_w$). The world price in this instance is represented by F, whereas B represents the quantity produced. A represents the quantity consumed domestically and AB the total volume exported. Consumer surplus is illustrated by the area enclosed by the domestic demand curve, the vertical axis and $D_w$. Producer revenue is represented by area $OBE_0F$. Imposition of an export ban shifts the equilibrium to point E1, at a price C and quantity produced still constant at B. In this case, the consumer surplus increases by area $CE_1GF$, however producer revenue declines by $CE_1E_0F$. Consequently, the net welfare loss is represented by $GE_1E_0$.

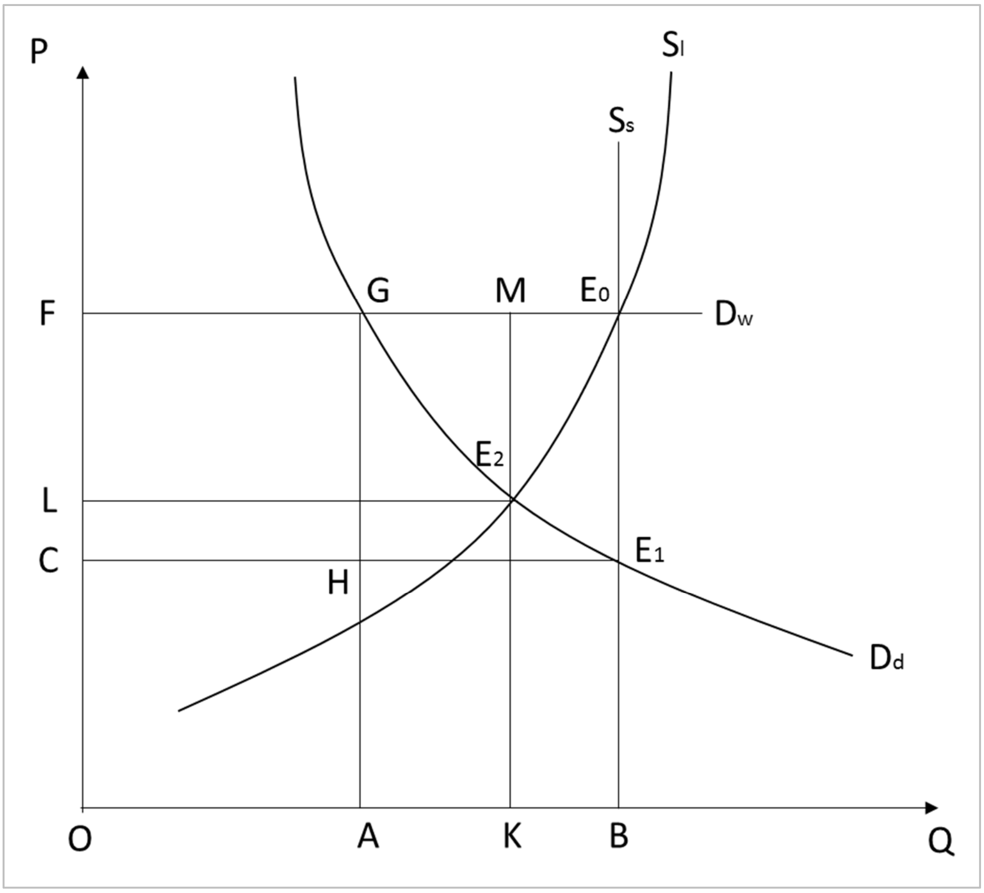

**Figure 5.2: Domestic impact of imposing an export ban**
Source: Mitra and Josling (2009)

Figure 5.2 clearly indicates how the relative elasticities of supply and demand are important determining factors in the magnitude of the welfare impact. It represents a static, short term view and fails to account for the dynamic response by producers in the long term. In Zambia, such impacts can be quantified based on the elasticities presented in Chapter 4. Zambian maize exports are not sufficient to move world prices, which make the small country assumption associated with Figure 5.2 valid, but its role in providing exports into neighbouring countries such as Zimbabwe still implies some negative impact on consumers in neighbouring countries. The model specification allows for such effects to be quantified, despite the lack of world price impact, whilst also illustrating the trade-flow implications of the imposed export controls. The dynamic nature of the model further allows quantification of the supply response in Zambia flowing from the imposition of export controls.

### 5.1.2 Implications of the regional drought in Southern Africa in 2016

The drought conditions experienced across most of Southern Africa in 2016 provided a scenario which prompted Zambia to impose an export ban and is therefore used to quantify the impacts of the policy response. Across most of Southern Africa, 2015 already provided a below average harvest, with shortfalls evident in South Africa, Zambia, Zimbabwe, Mozambique and Malawi. Markets were however well stocked following the bumper crops recorded in 2014, which dampened the price impact. Towards the end of 2015, indications of a strong El Nino event started raising concern for another below average year in 2016. Zambia in particular had exported a substantial share of its surplus stocks in 2015, implying that the impact of a second consecutive drought on prices would be far more severe.

As the season played out, these fears were realised, as South Africa recorded the lowest annual rainfall in more than a century. Harvests in Zimbabwe and Mozambique were also well below average levels, however favourable conditions in the North of Zambia resulted in a year on year increase in production from 2015 levels. Nonetheless, the crop remained short of the three-year average and well below what could be expected in a normal rainfall year. Figure 5.3 illustrates the projected production levels for 2016 based on normal trend yields, relative to the drought scenario that ultimately played out in the region. The impact was concentrated in Southern Africa, with little change evident in production levels across Eastern Africa.

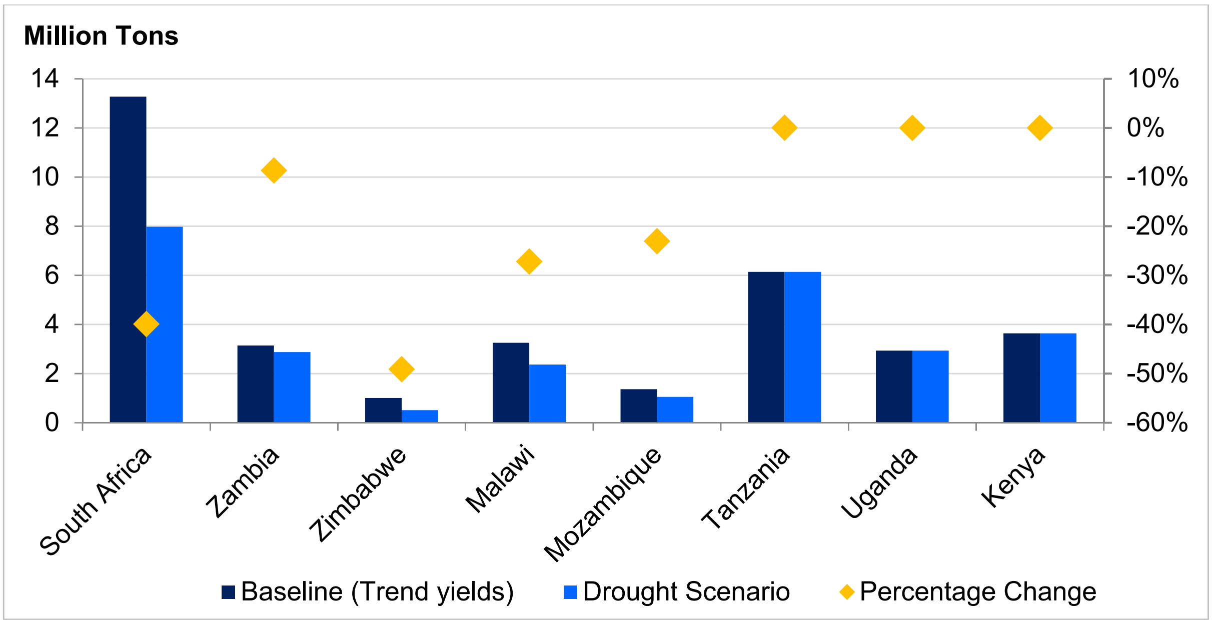

**Figure 5.3: Projected maize production in ESA in 2016 - Normal weather baseline vs. drought scenario**

In response to the regional shortage and to secure domestic supply, Zambia imposed export controls in April 2016. To illustrate the impact of these export controls, the simulation is conducted in 2 steps. The baseline outlook presented in Chapter 4 provides the starting point, reflecting simulated production levels, trade-flows and the associated price impacts based on projected trend yields. This is derived from an assumption of stable weather conditions and provides a benchmark against which the impact of the drought can be measured and understood. This baseline also assumes that trade is not restricted and occurs freely.

The first alternative scenario retains the assumption that trade occurs without restraint, but area and yield levels are reduced to bring production in line with the actual scenario that played out in the region. This yields regional price levels that “might have been” had export controls not been imposed. The second alternative scenario then reduces Zambian exports to simulate the imposition of export controls. Given the prevalence of informal trade, as well as the fact that trade controls are not always imposed for the full 12-month period, Zambian exports are reduced to 10% of the value simulated based on price differences between Zambia and the various destination countries. This results in total exports from Zambia of approximately 270 thousand tons in 2016. The absolute export volumes from Zambia to the various Southern African countries under both the baseline and trade control scenarios is presented in Table 5.1.

**Table 5.1: Zambian exports to selected destinations in 2016 drought – open borders vs. trade controls**

| Export destination | Drought: Open borders (Thousand tons) | Drought: Trade controls (Thousand tons) |
|---|---|---|
| Malawi | 7.23 | 14.45 |
| Mozambique | 10.13 | 2.06 |
| South Africa | 0.00 | 0.00 |
| Zimbabwe | 541.42 | 254.30 |
| Other | 0.77 | 0.20 |

### 5.1.3 Simulation results

The production shortfall illustrated in Figure 5.3 implied that South Africa, which is typically the largest surplus producer in the region, required substantial imports of both white and yellow maize, which also limited the extent to which it could supply white maize to the rest of the region. This left Zambia as the only significant surplus producer amongst Southern African countries and the consequent price increase affected all countries in Southern Africa (Figure 5.4). The biggest price impact in percentage terms is observed in Malawi, South Africa and Zambia, but in absolute terms, the increase is similar in all five Southern African countries. By contrast, prices in East African countries such as Uganda, Tanzania and Kenya remained largely unchanged due to the lack of changes in production levels.

The price response generated by the drought simulation highlights a key difference from what would be observed in a traditional price linkage approach. In a year when world prices declined, a price linkage approach would have yielded declining prices in the region, combined with higher imports. The alternative specification of using the South African price as a representative world price for white maize would have resulted in rising prices across all of the Southern and East African countries.

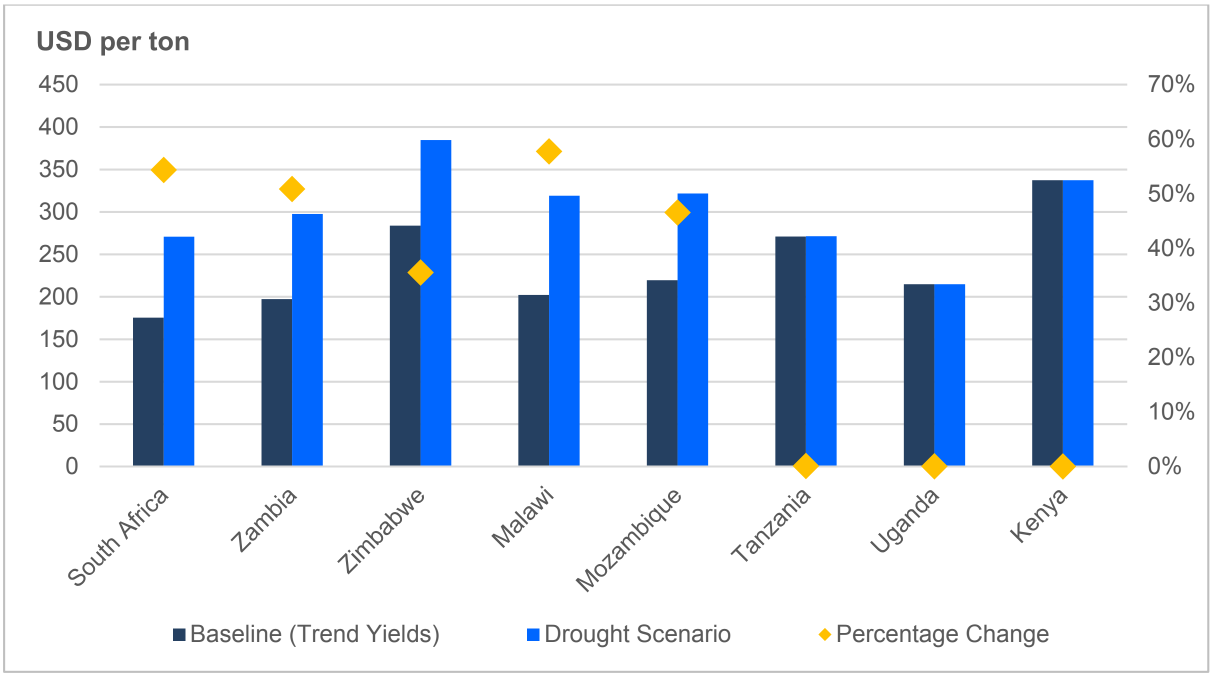

**Figure 5.4: Impact of drought on price levels in absence of trade controls**

The price increase in South Africa is a result of moving from export parity to import parity levels due to the production shortfall. Mozambique is a consistent importer of South African maize into Maputo in normal years, hence the South African price increase is also passed through to the Mozambican market. By contrast, the increase in Zambian prices is derived from increased regional import demand, more so than an inability to supply its domestic market. As the only remaining surplus producer in the region, prices increase in line with prices that can be attained in neighbouring countries. This creates a situation where the Zambian government reacts to secure domestic supply, but also to shield domestic consumers from the rising prices across the region. Imposing this response in the modelling framework yields a reduction in Zambian prices, but also an extended influence across the rest of the region.

Figure 5.5 presents the price impact of the drought shock, as well as the export control policy response across the five Southern African countries modelled. In Zambia, controlling exports has the desired effect of reducing domestic prices, which fall by more than 35% from the levels associated with the drought shock in an open border scenario. In neighbouring countries however, prices increase further due to the reduction in maize available for import. This is particularly true in Zimbabwe and Malawi, where prices increase by a further 4% and 2% respectively. In South Africa and Mozambique, the price increase is negligible, as South African is already expected to import significant quantities from outside the region in the open border scenario and while this volume increases as a result of the export controls imposed by Zambia, price movements are minimal due to the source of additional imports remaining the same. This result is based on the assumption that South Africa is able to procure white maize in the global market, or alternatively import more yellow maize for use in the animal feed market, which allows additional white maize exports into the region.

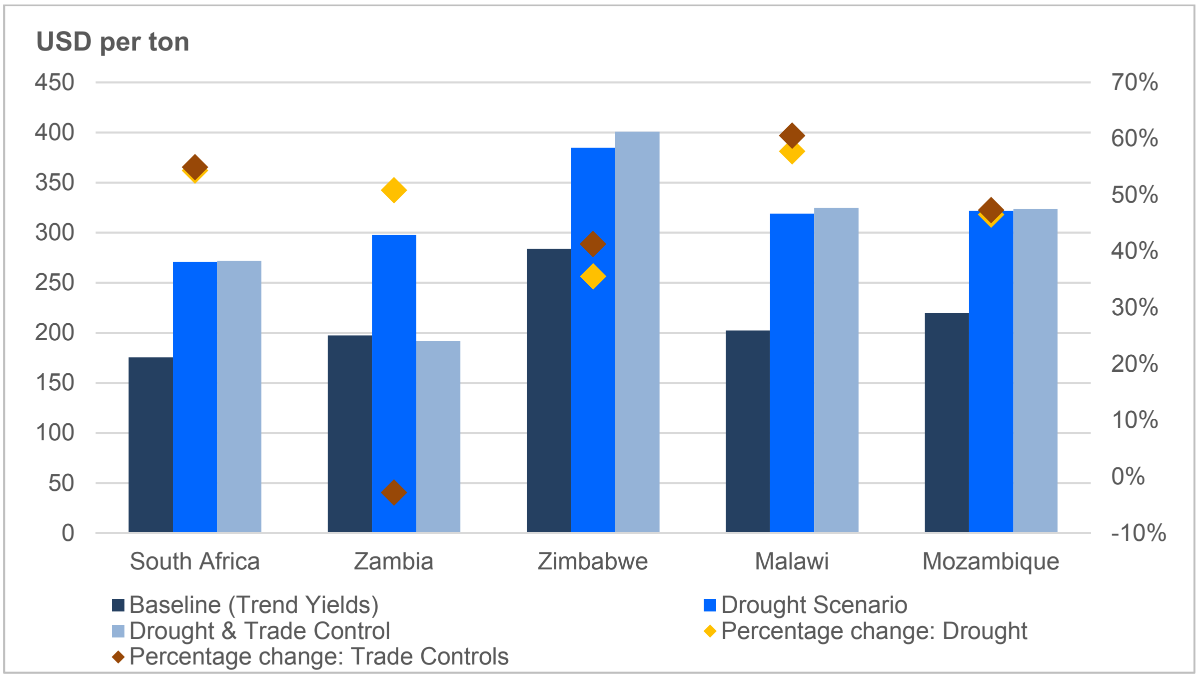

**Figure 5.5: Drought impact with the application of trade controls**

Price movements in Zimbabwe and Malawi are underpinned by the changes in trade flows that originate from the export controls. Figure 5.6 indicates that Zimbabwe has to procure imports from other sources, which comes at a premium relative to its usual imports from Zambia and results in higher domestic prices. The bulk of the deficit is filled by South Africa, with some imports accruing from outside the modelled region and some also procured in Malawi. This increase in export demand supports an increase in the Malawian maize price.

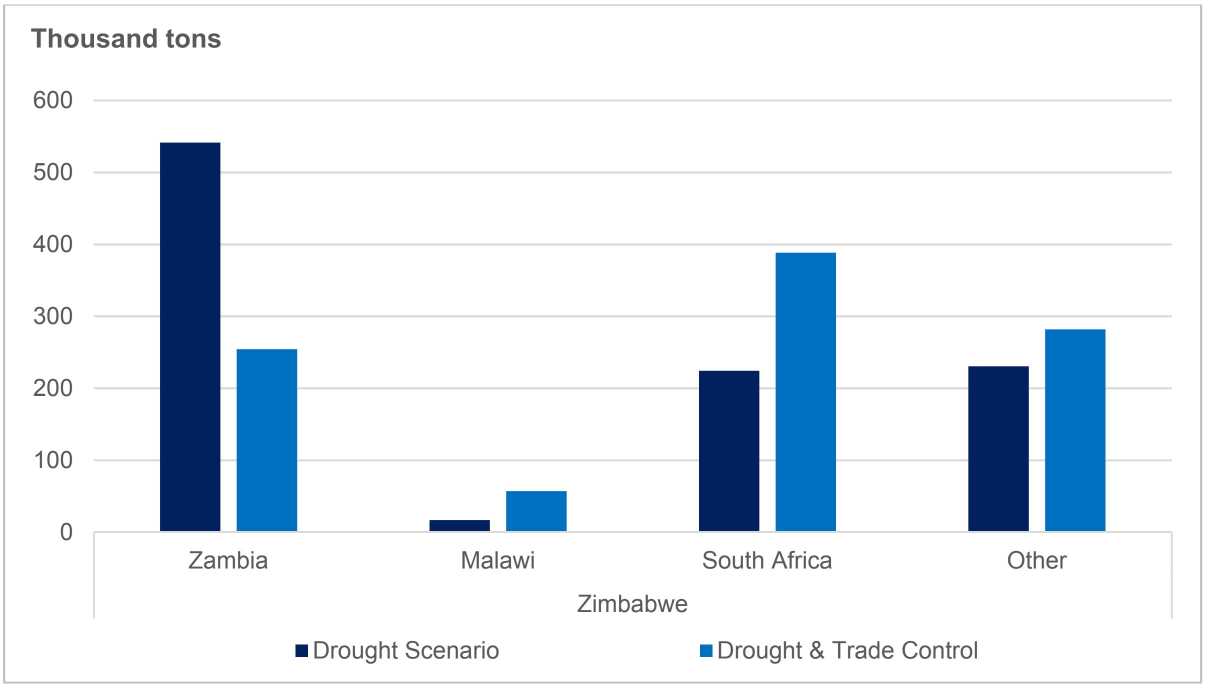

**Figure 5.6: Impact of trade controls on imports by Zimbabwe**

Within Zambia and across the region, the price impacts have important implications for supply and demand decisions, particularly for maize which represents the core food staple in the region. The objective of short term policies such as the export controls applied relate to ensuring domestic supply at reasonable prices, which implies a benefit to consumers. This is evident in Figure 5.7, which illustrates the change in consumption under drought conditions when export controls are applied, relative to the open border but still drought affected scenario across the five Southern African countries. In Zambia, consumption increases markedly due to lower prices, whereas a reduction in consumption is evident across all the other countries where prices increased significantly. In neighbouring countries such as Zimbabwe, which rely on Zambia for imported maize, the negative impact of the drought is exacerbated by the imposition of trade controls in Zambia. The positive impact for Zambian consumers is however much larger than the negative impact on consumers in neighbouring countries.

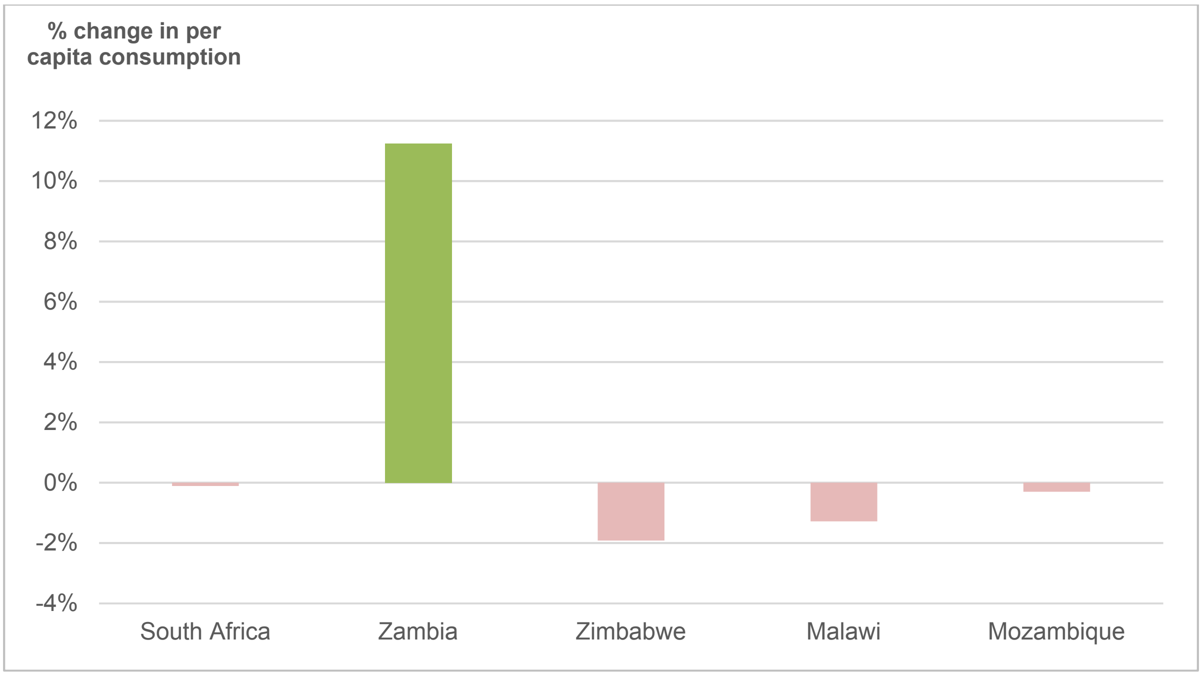

**Figure 5.7: Change in per capita maize consumption in drought scenario: Export controls vs. open borders**

Numerous researchers, such as Chapoto & Jayne (2009), Jayne (2012) as well as Jayne and Tschirley (2009) have indicated however that this support to consumers comes at the expense of producers and Mitra & Josling (2009) suggested that the net impact on welfare is negative. This is particularly relevant in African countries, where a large number of smaller producers depend on agriculture for their livelihood. In an open market situation, a drought induced reduction in output volumes results in significant price increases, particularly for food staples, which are typically associated with inelastic demand. This increase in prices compensates for the loss in output and depending on specific supply and demand elasticities, producer revenue could even increase. When exports are controlled to reduce domestic prices, this market based mechanism is removed and producers face lower volumes at reduced prices. Figure 5.8 illustrates this impact, through the change in gross revenue in the drought and export control scenario relative to the drought affected open trade scenario in the five Southern African countries included in the model.

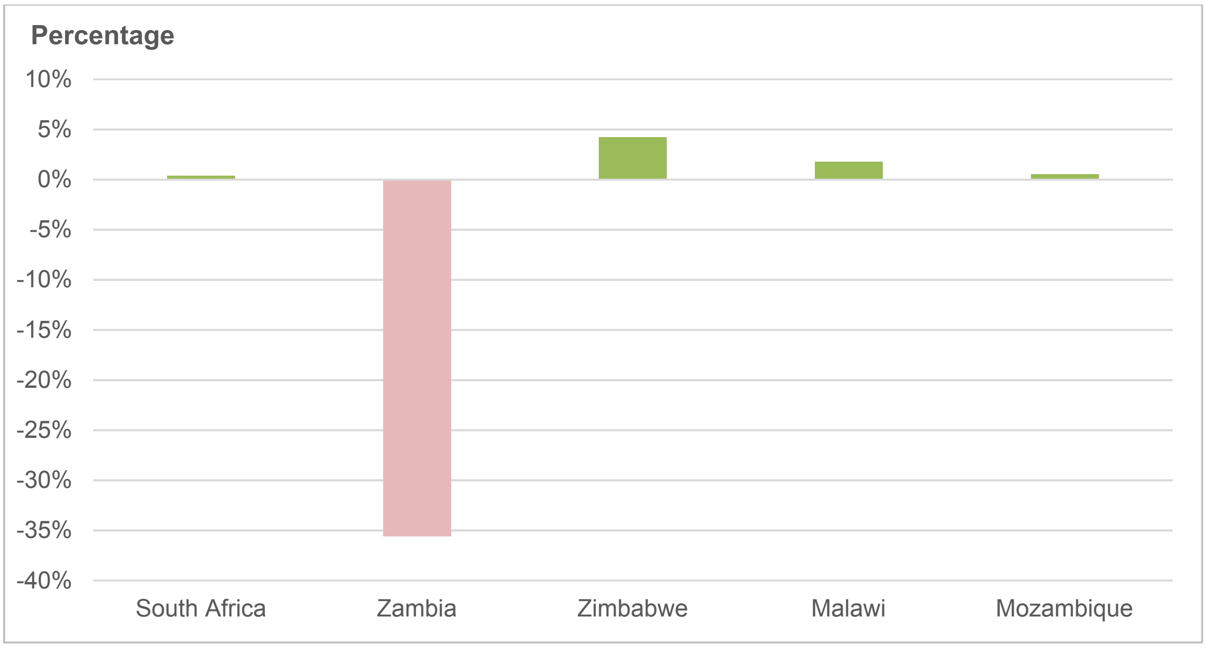

**Figure 5.8: Percentage change in gross revenue in drought scenario: Export controls vs. open borders**

The simulated price impact results in higher gross revenue relative to the open trade situation in South Africa, Zimbabwe, Malawi and Mozambique, whereas gross revenue declines in Zambia. The implication is that, due to the export controls, Zambian producers do not receive the benefit of higher prices in a year when output volumes are already reduced, resulting in a 35% decline in gross revenue relative to the open trade scenario. This reduction in revenue from maize will not incentivize production in 2017, leading in a smaller area response relative to the open border scenario (Figure 5.9).

Given the limited price response, the increase in area in South Africa relative to the open trade scenario is limited, but a response is evident in Zimbabwe, where the price impact of the Zambian export controls was the largest. The decline of almost 5% in Zambian area planted in 2017 under the trade control scenario relative to the open trade situation under drought conditions suggests that in the long run, the discretionary imposition of short term export controls are detrimental to expanding production in Zambia, which results in it producing a smaller share of regional maize production in subsequent years. In the short run, consumers are indeed better off, but the loss of producer revenue far exceeds the benefit to the consumer.

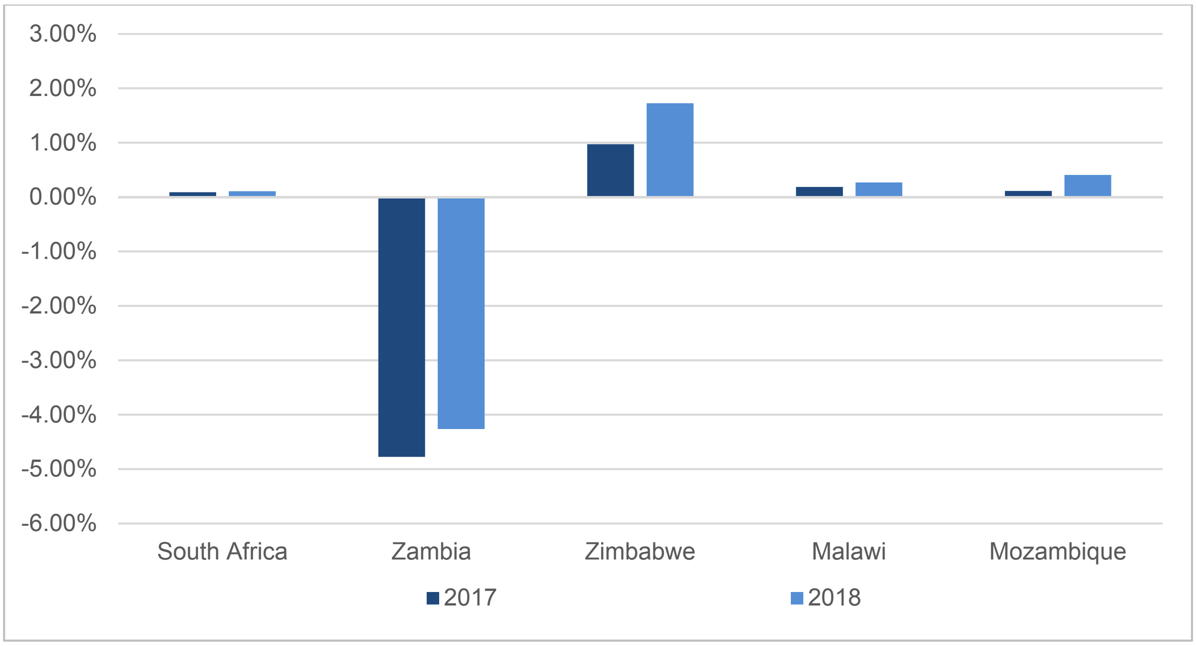

**Figure 5.9: Change in area response in drought scenario: Export controls vs. open borders**

### 5.1.4 Concluding remarks on the impact of export control

Literature related to the impact of export controls in ESA maize markets remains sparce, especially when related to wider regional impacts than the country in which its applied. Within the existing literature, a lack of consensus related to cross border price impacts remains, with Porteous (2012) as well as Dabalen & Paul (2014) noting co-movement of prices in markets that trade regularly even when exports are banned. Such findings contrast with theoretical expectations and disagreement remains on the direction of price movements when evaluating historical export bans. This suggests that the regional impacts of such bans is yet to be quantified satisfactorily and warrants further research.

Despite various methodological approaches, which include single equations, CGE model simulations and household survey data analysis, greater consensus emerges amongst studies focused on a single country where the export ban is applied. Authors consistently point to reduced investment and a lack of production growth, but conclusions remain limited in that they fail to account the wider regional context. Arguing that Zambia has become too important a regional supplier over the past decade to ignore the wider impacts of its policy actions, this section applied a partial equilibrium framework that examines both the in-country impacts of export controls in Zambia through the 2016 drought, as well as the cross-border effects.

The dynamic partial equilibrium model applied considers both the impact of the export controls imposed by Zambia and the response by producers and consumers in Zambia and neighbouring countries. The model structure further allows for quantification of alternative trade flows in response to the policy imposed. In country impacts in Zambia are similar to prior studies, with a reduction of 35% in domestic prices relative to the baseline simulation. This compares to a decline of 17% in Tanzania reported by Dabalen and Paul (2014) and a decline of 20% to 50% depending on the severity of the export reduction reported by Dorosch *et al.* (2009) in Zambia. Cross border price impacts from the reported simulations contrast reviewed literature (Dabalen & Paul, 2014; Porteous, 2012) in that prices in typical export destination are found to increase due to export controls. This is supported by theoretical expectations, as well as negative global impacts reported by Mitra and Josling (2009), Bouet and Laborde (2010) as well as Martin and Anderson (2012).

Having confirmed the negative aggregate impact of imposing export controls in ESA, both within the applying country and across borders, but also noting the reasons for continued application, one must question possible alternatives. Haggblade *et al.* (2008), Jensen and Sandrey (2015), as well as Morrison and Saris (2016) note the potential benefits from keeping borders open and encouraging intra-regional trade in Africa, but few have suggested alternatives that achieve the same price reducing effect for consumers. Domestic consumption management measures, such as government procurement at market prices combined with subsidized sale to low income consumers will protect the consumer without the direct price impact on producers, but the fiscal burden falls to government (Mitra & Josling, 2009), which must also generate revenue from tax income. In least developed countries, where agriculture continues to account for a large share of the economy, the difficulties with making such a program viable through taxation of luxury goods is clear. Supply augmenting measures, such as increased investment in irrigation and other agricultural infrastructure tends to be neglected by cash strapped governments (Mitra & Josling, 2009). Policies that redistribute welfare from producers to consumers do not encourage private investment into such measures. Hence the well documented need to prioritize production and productivity growth due to its long term benefits for both consumer and producer (Dorosh *et al.,* 2009; Mitra & Josling, 2009; Haggblade *et al*., 2008).

### 5.2 Long term application: Productivity gains in Tanzania

Across most of Sub-Saharan Africa, strong growth in agricultural output over the past decade has accrued from area expansion and intensification of cropping systems as opposed to large scale improvements in productivity (NEPAD, 2014; Brink & Eva, 2009). This has also been true in the maize sector, where absolute yield levels remain low in the global context and few countries have been able to match the average annual yield growth attained globally. Figure 5.10 depicts average yield levels, as well as average annual growth in yields across the eight ESA countries included in this study, relative to the global average. Despite a significantly smaller base, only South Africa, Uganda, Malawi and Zambia have been able to match or exceed global growth rates between 2000 and 2015, with Kenya, Tanzania, Mozambique and Zimbabwe all recording growth of 1% per annum or less. This is merely half of the annual improvement achieved globally. In absolute terms, average yields observed in Tanzania between 2000 and 2015 remain a mere 26% of the average global level.

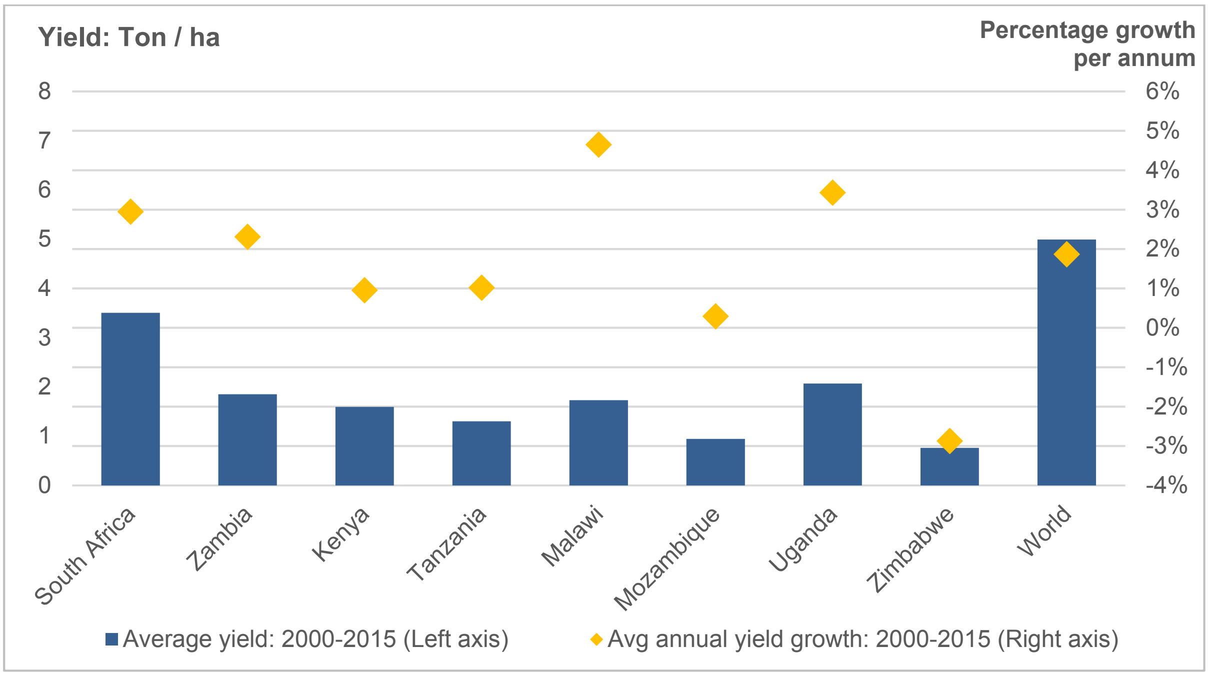

**Figure 5.10: Maize yields in ESA compared to global average**
*Source: OECD-FAO (2017) and ReNAPRI (2017)*

The problem of slow productivity growth has been acknowledged in the region and improvements prioritised in the Malabo declaration on accelerated agricultural growth. In Tanzania, which cultivates the largest area to maize of all countries included in this study, yield gains have been disappointing, improving from 1.07 tons per hectare in 2000 to merely 1.6 tons per hectare in 2015. This continued yield gap, combined with the large area under production, points to significant potential to increase output, supplying not only its own food security needs, but also that of other countries in East Africa.

Acknowledging the potential expansion, the model specified in Chapter 4 is applied to a long term alternative scenario to illustrate the impact of possible yield improvements in Tanzania on domestic producers, consumers and regional trade-flow patterns. This serves to highlight not only the potential impacts of productivity improvements, but also another instance where the model specified in Chapter 4 provides a credible simulation of an alternative future outcome. Within a traditional price linkage approach, improved productivity would have no impact on domestic prices, which contrasts with the evidence from Zambia, where rising production volumes over the past decade moved it from a deficit to a surplus producer, leading to a substantial reduction in prices relative to the rest of the region (Table 5.2). As the most frequent destination for Zambian exports, Zimbabwe also received some benefit from the reduced prices in Zambia.

**Table 5.2: Price comparison: average 2011 - 2015 vs. average 2006 - 2010**

| Country | Average 2006-2010 (a) | Average 2011-2015 (b) | % change: (b) vs. (a) |
|---|---|---|---|
| World Price: US Gulf | 152.03 | 234.68 | 54.37% |
| South Africa: Randfontein White | 195.54 | 236.93 | 21.16% |
| Kenya: Nairobi | 267.75 | 359.60 | 34.31% |
| Zambia: Lusaka | 256.78 | 236.43 | -7.92% |
| Tanzania: Arusha | 218.10 | 285.91 | 31.09% |
| Malawi: Lilongwe | 246.64 | 274.11 | 11.14% |
| Mozambique: Average | 260.29 | 299.48 | 15.06% |
| Uganda: Kampala | 222.06 | 266.60 | 20.06% |
| Zimbabwe: Harare | 301.83 | 298.74 | -1.02% |

### 5.2.1 Potential for productivity gains in Tanzania

African policy makers have set themselves the goal of doubling agricultural productivity by 2025 (AU, 2014), but what exactly a doubling of productivity would entail remains somewhat ambiguous. Productivity is measured as the ratio of agricultural outputs to agricultural inputs and within the maize sector, crop yields represent an indicator for productivity. Yield improvements can also be used to simulate an alternative future outcome related to accelerated productivity gains over the next decade. Prior to simulating such an alternative future outcome, the potential for yield improvements must first be evaluated and understood.

Yield potential for maize production in Tanzania can be quantified through climatic suitability, as defined by the Global Agro-Ecological Zones (GAEZ) database of the FAO. The climatic suitability is defined according to soil, terrain and climatic considerations, based on knowledge of crop requirements and prevailing soil conditions. Essentially, soil suitability procedures quantify to what extent soil conditions match crop requirements under different circumstances related to input and management. Figure 5.11 overlays the current maize production area in Tanzania with climatic suitability derived from an intermediate input regime, which assumes improved management and a partly market orientated production system. Production is based on improved varieties, manual labour with hand tools and animal traction, combined with some, but not full mechanization. Labour intensity would be mid-range and the production system applies some fertiliser and utilises chemical pest, disease and weed control. Furthermore, adequate fallows are observed and some conservation measures applied. Under this management system, the potential yields in most production areas are above 2 tons per hectare.

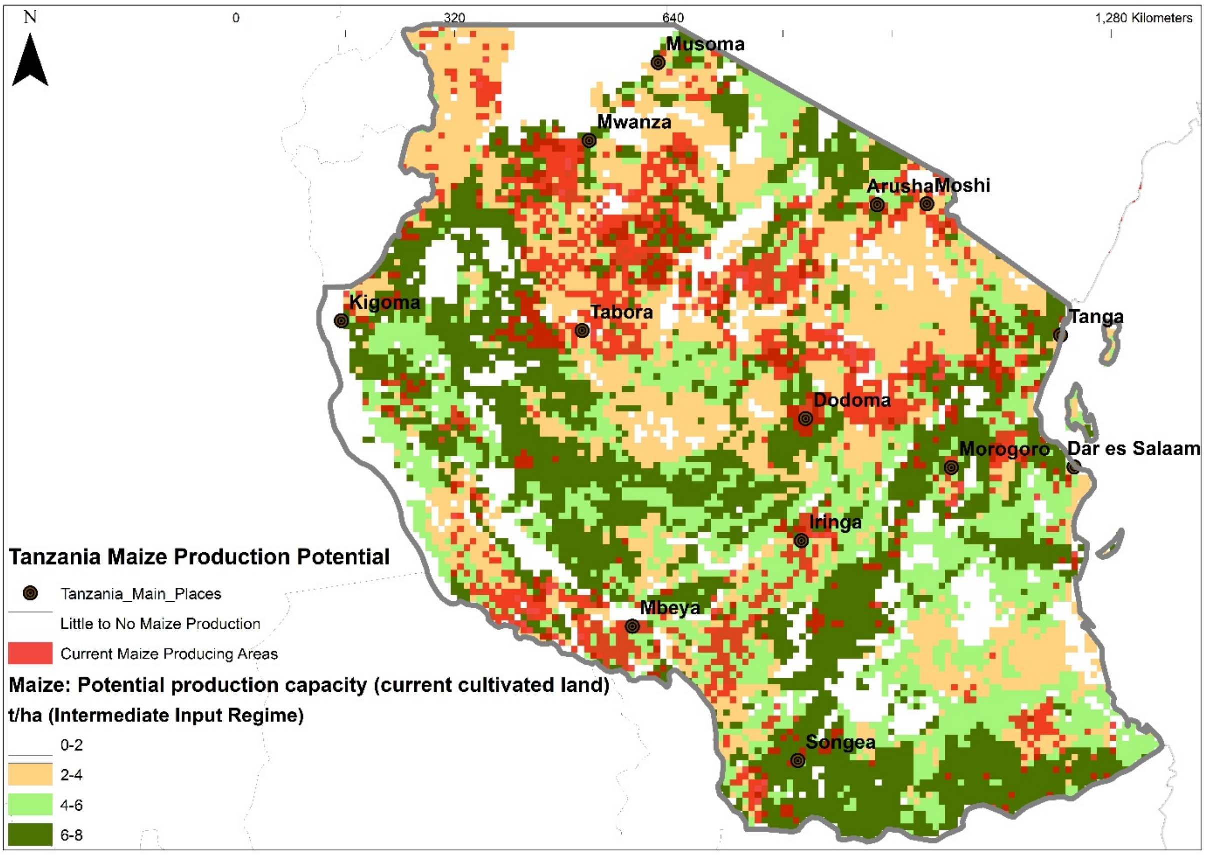

**Figure 5.11: Current production and climatic suitability for maize production in Tanzania under an intermediate input regime**
*Source: Compiled from GAEZ (2017)*

Against this backdrop of undoubted potential, the question remains why yield levels remain so low. The sector is dominated by smallholder producers operating on an average farm size of 0.9 to 3 hectares. These producers contribute more than 75% of total agricultural output and rely on traditional production technologies (Anderson,Marita & Musiime, 2016). As such, the level of agricultural intensification remains low and AGRA (2016) indicates that, based on World Bank survey data, less than 10% of these producers have access to extension services. The share of producers employing improved inputs such as fertiliser, pesticides and herbicides is also below 10%, with almost 16% making use of improved seed.

**Table 5.3: Use of improved inputs in selected Sub-Saharan African countries**

| Country | Survey year | Use of agricultural inputs and access to extension services (% of households) | | | | | Cereal yield (t/ha): 2005-2014 | Area under cereals (million hectares) |
|---|---|---|---|---|---|---|---|---|
| | | Improved seed | Fertiliser | Manure | Pesticides / Herbicides | Access to extension services | | |
| Tanzania | 2012/13 | 15.8 | 9.4 | 13.3 | 9.4 | 6.3 | 1.4 | 5.45 |
| Malawi | 2013 | 55.7 | 74.2 | 19.8 | 5.7 | 63.1 | 1.8 | 1.79 |
| Uganda | 2011/12 | 27.7 | 5.6 | 15.4 | 14.7 | 27.9 | 1.9 | 1.67 |
| Ghana | 2009/10 | 12.8 | 10.9 | 3.8 | 18.2 | 9.8 | 1.6 | 1.52 |
| Nigeria | 2012/13 | 27.8 | 45.0 | - | 19.3 | 12.0 | 1.5 | 16.87 |
| Ethiopia | 2011/12 | 16.8 | 7.4 | 9.1 | 24.0 | 32.1 | 1.8 | 9.32 |

*Source: World Bank, quoted in AGRA (2016) & FAOSTAT (2016)*

The current input system employed in Tanzania therefore relates more closely to the low input regime specified in the climatic suitability parameters. Under the low input regime, traditional management practices are assumed and the production system is largely subsistence based rather than market orientated. Production is based on the use of traditional cultivars, employing labour intensive cultivation techniques. No additional nutrients or chemicals are applied and conservation measures are minimal. Under this assumption, the climatic suitability for maize is represented in Figure 5.12, which places the bulk of current production in the 0.8-2 ton/ha or 2-2.8 ton/ha range.

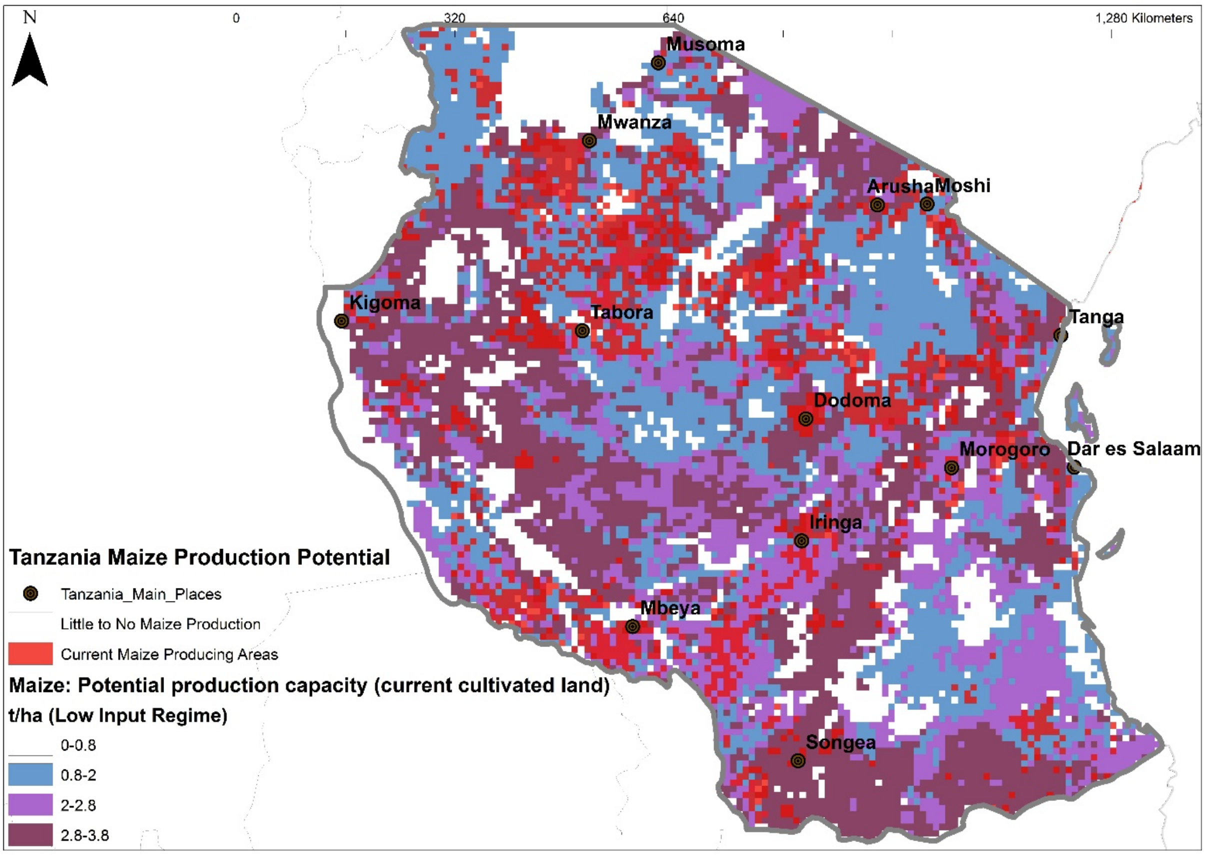

**Figure 5.12: Current production and climatic suitability for maize production in Tanzania under a low input regime**
*Source: Compiled from GAEZ (2017)*

Increasing the share of producers that make use of improved inputs would therefore shift the potential from what is illustrated in Figure 5.12 closer to the levels presented in Figure 5.11. The benefits of increasing the share of producers making use of improved inputs is further illustrated in Figure 5.13, which highlights the returns per hectare as a measure of crop productivity under different input regimes. In Tanzania, producers making use of improved seed, fertiliser, pesticides and herbicides earned more than 4 times the return per acre relative to producers making use of local seed with no additional inputs. Benefits also increased in other countries as input use intensifies.

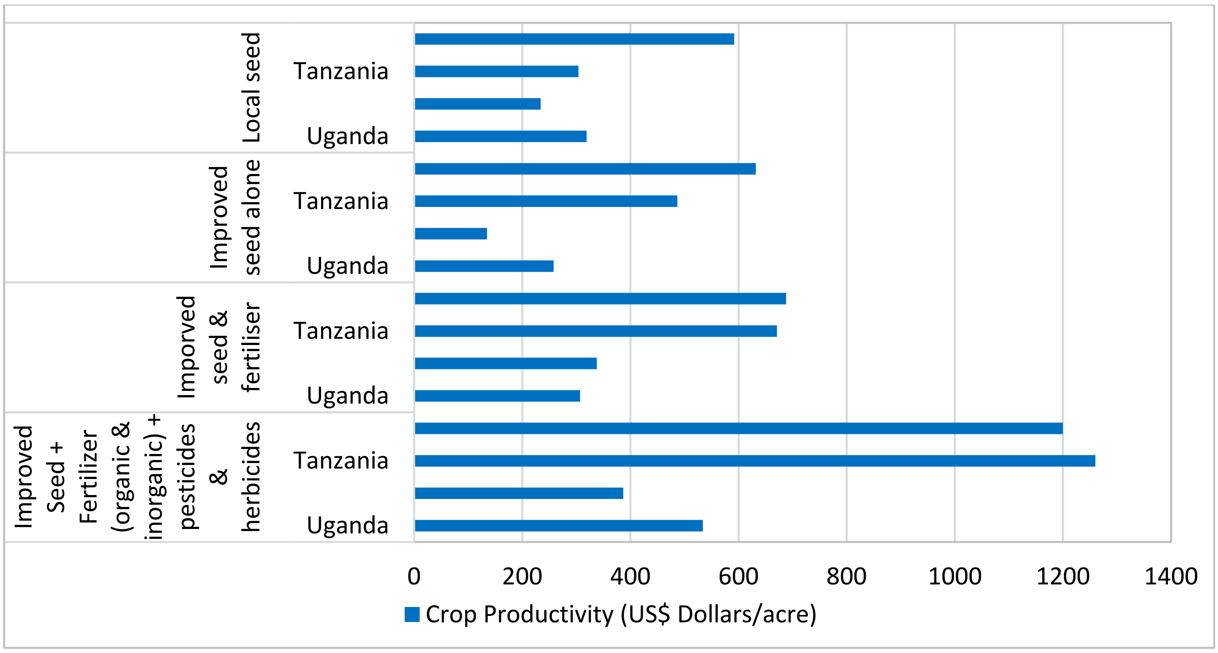

**Figure 5.13: Input intensification, crop productivity & returns to acre**
*Source: AGRA (2016)*

Recognizing the benefits of input intensification and following the inefficiencies recognized in the previously employed National Input Voucher System (NAIVS), the Tanzanian government instituted a new system of agricultural support in 2014. The new system is loan based and targets registered farmer groups through loan guarantees, allowing a fixed interest rate of 4% - well below the normal lending rate of 16.2% reported by the World Bank in 2014 (ReNAPRI, 2014). These changes align with the prioritisation of agriculture in Tanzania's National Development Vision 2025, which envisages a shift from a low productivity agriculture economy to a semi-industrialized economy led by modern and productive agricultural activities.

Changes in policy support could improve small scale farmer productivity if it succeeds in increasing the intensity of improved input use, but recent evidence also points to an emergent investor farmer operating on farm sizes between 5 and 100 hectares (Jayne *et al*., 2016). Table 5.4 indicates that, while small farms below 5 hectares still dominate the sector, farms exceeding 5ha have increased since 2008 and account for a rising share of total farmland below 100 hectares. Jayne *et al*. (2016) notes that the rise in larger holdings reflects an increased interest in agricultural land by urban based, politically connected professionals. The extent to which this trend in increasing land size improves productivity will depend on the share of such land entering or remaining in agricultural production. Commercial orientation on these emerging medium scale farms, combined with changes in support policy to small scale producers has the potential to improve Tanzanian yield growth in the coming decade relative to the past. Such improvements would be expected to result in a significantly different price path relative to the baseline presented in Chapter 4.

**Table 5.4: Changes in farm structure in Tanzania**

| **Tanzania** | **Number of farms (% of total)** | | | | **% growth in number of farms between initial and latest year** | **% of total operated land on farms between 0-100 ha** | |
|---|---|---|---|---|---|---|---|
| **Size** | **2008** | | **2012** | | | **2008** | **2012** |
| 0 - 5 ha | 5454961 | (92.8) | 6151035 | (91.4) | 12.8 | 62.4 | 56.3 |
| 5 - 10 ha | 300511 | (5.1) | 406947 | (6.0) | 35.4 | 15.9 | 18 |
| 10 - 20 ha | 77668 | (1.3) | 109960 | (1.6) | 41.6 | 7.9 | 9.7 |
| 20 - 100 ha | 45700 | (0.7) | 64588 | (0.9) | 41.3 | 13.8 | 16 |
| Total | 5878840 | | 6732530 | | 14.5 | 100 | 100 |

*Source: Jayne et al. (2016)*

### 5.2.2 Impacts of productivity gains

The benefits of productivity gains in the agricultural sector have been well stated in literature (Dorosch *et al*., 2009; Mitra & Jossling, 2009; Haggblade *et al*., 2008), but the impact of the increased production on prices, particularly in Africa where many markets are localized and isolated, has not received the same attention. This may be attributable to the typical assumption of perfectly elastic export demand, which would imply that prices remain unchanged in the event of increased production, with export volumes increasing to absorb additional supply. While extremely elastic demand for exports may seem reasonable in theory, Bredahl *et al.* (1979) indicates that price transmission is not perfect, due to the presence of transaction costs, which in turn reduces export elasticities. This is particularly relevant in Africa, where transport costs, an important driver of total transaction costs, are accepted as high (OECD-FAO, 2016) and factors such as poor infrastructure increase the cost of trade. Inelastic export demand would support the notion that increased supply will impact on domestic price levels, which is also consistent with the findings of Baffes *et al.* (2015) that domestic factors exert a greater influence on Tanzanian maize prices than external factors.

Changes to existing production systems, or the adoption of new technology that lead to yield improvements in Tanzania would effectively imply an outward shift of the domestic supply curve, which is illustrated graphically in Figure 5.14. $S_b$ represents the baseline supply curve, which is shifted outwards to $S_s$ in an alternative scenario of improved productivity. Under an assumption of perfectly elastic export demand ($D_w$), which is consistent with a traditional price linkage modelling approach, maize prices in Tanzania will remain unchanged at level F and hence domestic consumption will also remain unchanged at quantity A. Exports will however increase from quantity AC to quantity AB.

Tanzania produces predominantly white maize, which would typically be exported into the rest of the ESA region. For the reasons described, the demand for such exports will be less than perfectly elastic and is therefore downward sloping, but still more elastic than domestic demand ($D_d$). Total demand is then effectively represented by $D_r$ as opposed to $D_w$, and a shift in domestic supply from $S_b$ to $S_s$ will reduce domestic prices in Tanzania to level J. Consequently, domestic consumption will increase from quantity A in the baseline to quantity D in the accelerated productivity scenario, while exports increase from quantity AC to quantity DM.

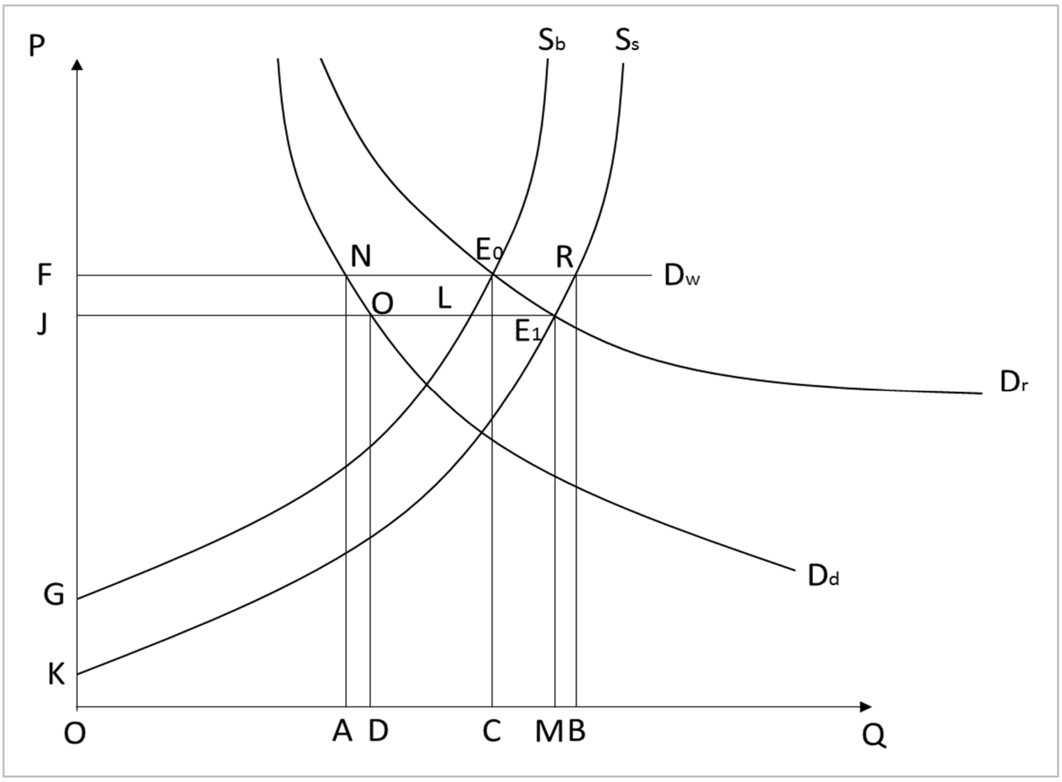

**Figure 5.14: Potential impact of improved yields in Tanzanian maize production**

Within the context of Figure 5.14, welfare implications can be considered in terms of producer and consumer surplus. At a regional level, the gains to consumer surplus can be represented by area enclosed by $FE_0E_1J$. Of this gain, FNOJ would accrue to domestic consumers in Tanzania, whereas the balance would be a benefit to consumers in the rest of the region. As a result of the yields gains, producer surplus would increase by area $GE_0RK$. At the same time, the lower price would result in a loss in producer surplus of area $FE_0LJ$. This loss in producer surplus is however transferred as a gain in consumer surplus and hence the total societal welfare implication would remain positive. The magnitude of these relative shifts in welfare is dependent on the relevant elasticities of the demand and supply curves. It can therefore be quantified based on the model structure and elasticities specified in Chapter 4.

### 5.2.3 Simulation results

The baseline presented in Chapter 4 assumes that the rate of yield growth attained historically will continue over the 10-year outlook period. The possible yield gains alluded to in Section 5.2.1 however would result in a vastly different outcome, both in terms of prices and trade-flows. In line with the objectives of the Malabo declaration, an alternative scenario is specified where the rate of yield growth projected in the baseline for Tanzania is doubled over the course of the next 10 years. Using the model specified in Chapter 4, the domestic, as well as neighbouring country market impacts of accelerated yield growth in Tanzania are simulated in a first step. Secondly, it illustrates the difference in impact under alternative scenarios where typical barriers to trade, such as import tariffs and transportation costs are reduced.

Derived from the past decade, the baseline presented in Chapter 4 projected yield growth of 2.8% per annum from 2016 to 2025 in Tanzania, resulting in a national average yield of 1.94 tons per hectare by 2025. Doubling this rate of growth for the alternative scenario results in average annual growth of 5.7% per annum, which would bring the national average yield to 2.51 tons per hectare by 2025. This represents an improvement of 30% by 2025 relative to the baseline and results in a significant decline in domestic prices. Domestic area cultivated to maize declines as a result and hence by 2025, total Tanzanian maize production increases less than yields, expanding by 18% relative to the baseline.

The effect of increased production in Tanzania on domestic and neighbouring country prices is presented in Figure 5.15, while Table 5.5 presents the percentage change in maize prices under the accelerated yield growth scenario relative to the baseline. Tanzania typically supplies surplus maize into Nairobi, while Kenya also imports maize from Uganda into its western markets. Consequently, the average decline of 33% in Tanzanian maize prices from 2017 to 2025 relative to the baseline is also transmitted into Kenya and Uganda, where prices decline by an average of 13% and 9% respectively between 2017 and 2025.

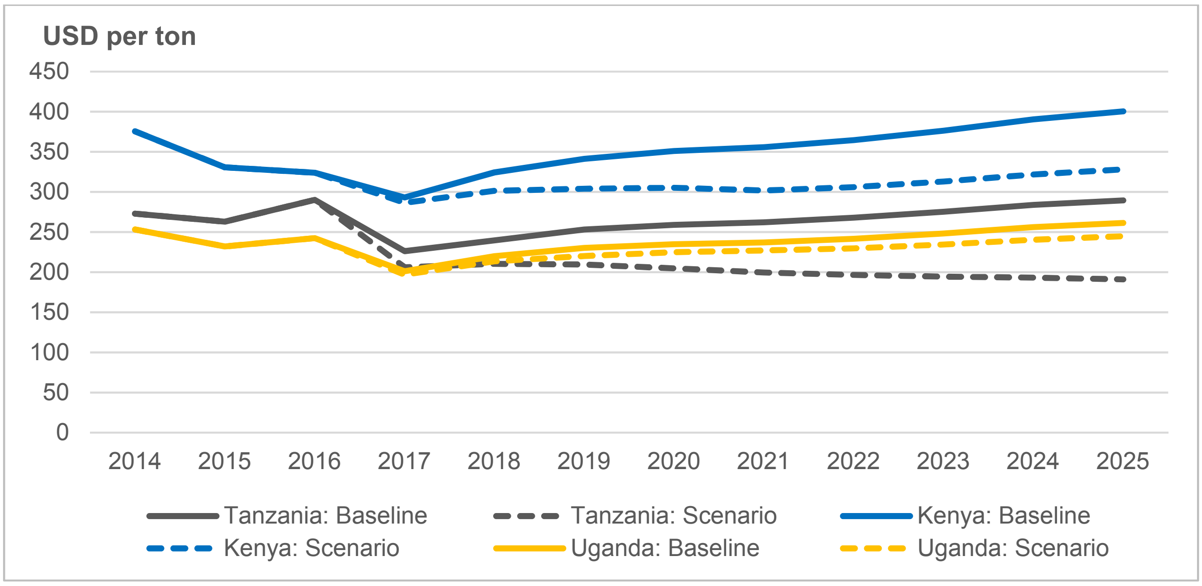

Figure 5.15: Maize prices in East Africa - baseline vs. scenario

**Table 5.5: Percentage change in prices in East Africa - baseline vs. scenario**

| Country | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 |
|---|---|---|---|---|---|---|---|---|---|
| Tanzania | -9% | -13% | -17% | -21% | -24% | -27% | -30% | -33% | -35% |
| Kenya | -2% | -5% | -7% | -8% | -8% | -9% | -9% | -11% | -11% |
| Uganda | -2% | -5% | -5% | -6% | -6% | -6% | -7% | -8% | -7% |

The reduction in neighbouring country's price levels results from substitution in Kenyan imports. Under the baseline, Kenya is projected to source 388 thousand tons of maize from Tanzania by 2025, supplemented by 382 thousand tons from Uganda and 341 thousand tons from outside of the ESA region. Under the alternative scenario, and the associated reduction in prices in Tanzania, Kenya is projected to import more than 1.2

million tons from Tanzania by 2025, supplemented by merely 169 thousand tons from Uganda and less than 30 thousand tons from outside of the ESA region (Figure 5.16). As a result, Kenyan prices decline and with the reduction in Kenyan import demand for Ugandan maize, prices in Uganda also decline, despite the lack of direct trade between Uganda and Tanzania.

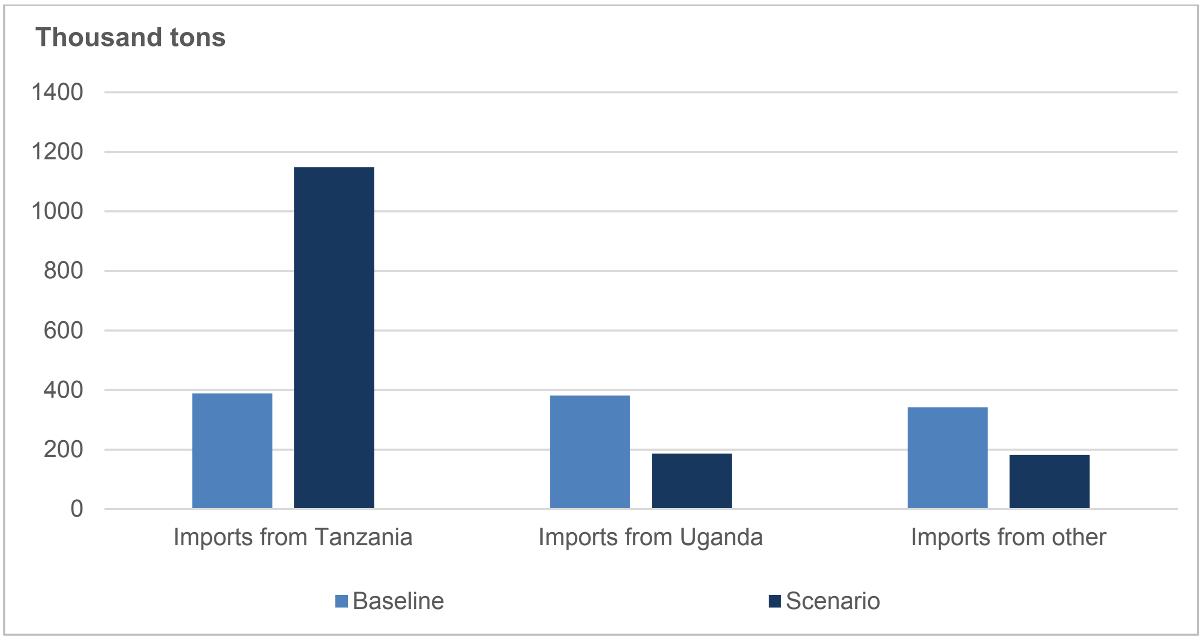

**Figure 5.16: Kenyan maize imports in 2025 - baseline vs. scenario**

Acceleration of baseline yield growth brings Tanzanian prices in line with the world reference price, as well as the South African white maize price by 2025. The high cost of trade within the region however inhibits trade initiation beyond its East African neighbours and therefore also limits price impacts to the three East African countries included in the model. The Malabo declaration however also expresses a further objective of tripling intra-regional trade in Africa. Given that all modelled countries are members of either SADC, COMESA or the EAC and Tanzania is a member of all three, intra-regional tariffs are already zero rated. Consequently, the scenario related to reduced trade costs only reflects removal of tariffs outside the ESA region and investment to reduce transportation costs. In the scenario, the cost of transportation is reduced to 80% of the baseline level in 2018, followed by 70% of the baseline level in 2019, 60% of the baseline level in 2020 and 50% of the baseline level in 2021. From 2022 to 2025, it is maintained at 50% of the baseline level. The reduction in transport cost is applied across the entire modelled region.

Table 5.6 presents the trade impact of the productivity scenario in isolation, and in combination with measures to reduce the cost of trade. It highlights the volumes exported from Tanzania to other countries included in the simulation model, as well as outside of the ESA region by 2025. In a scenario where transportation rates are reduced, significant exports are initiated to Zambia, Malawi and Northern Mozambique. The reduction in transportation rates is further also sufficient to initiate some exports outside of the ESA region.

**Table 5.6: Tanzanian exports in 2025 to various destinations under different scenarios**

| Country | Baseline | Scenario 1: Increased yield | Scenario 2: Increased yield and transport cost reduction |
|---|---|---|---|
| **Volume imported from Tanzania – thousand tons** | | | |
| South Africa | 0.00 | 0.00 | 0.00 |
| Zambia | 0.00 | 2.56 | 35.30 |
| Malawi | 0.00 | 2.86 | 67.05 |
| Mozambique | 0.00 | 0.00 | 20.95 |
| Kenya | 343.98 | 1235.84 | 1147.97 |
| Uganda | 0.00 | 0.00 | 4.77 |
| Zimbabwe | 0.00 | 0.00 | 0.00 |
| Other | 5.00 | 5.00 | 35.88 |

The trade-flows associated with the scenario where transportation rates are reduced also widens the price impact from the productivity gains achieved in Tanzania. However, the lower transportation rates also reduce the cost of trade to other importing countries such as Zimbabwe, which sources import from Zambia, but gains from a lower price for such imports following the reduction in transportation costs. Consequently, increases in per capita maize consumption accrue to all net importing countries in the region (Figure 5.17), though all of this increase cannot be attributed to the productivity gains achieved by Tanzania.

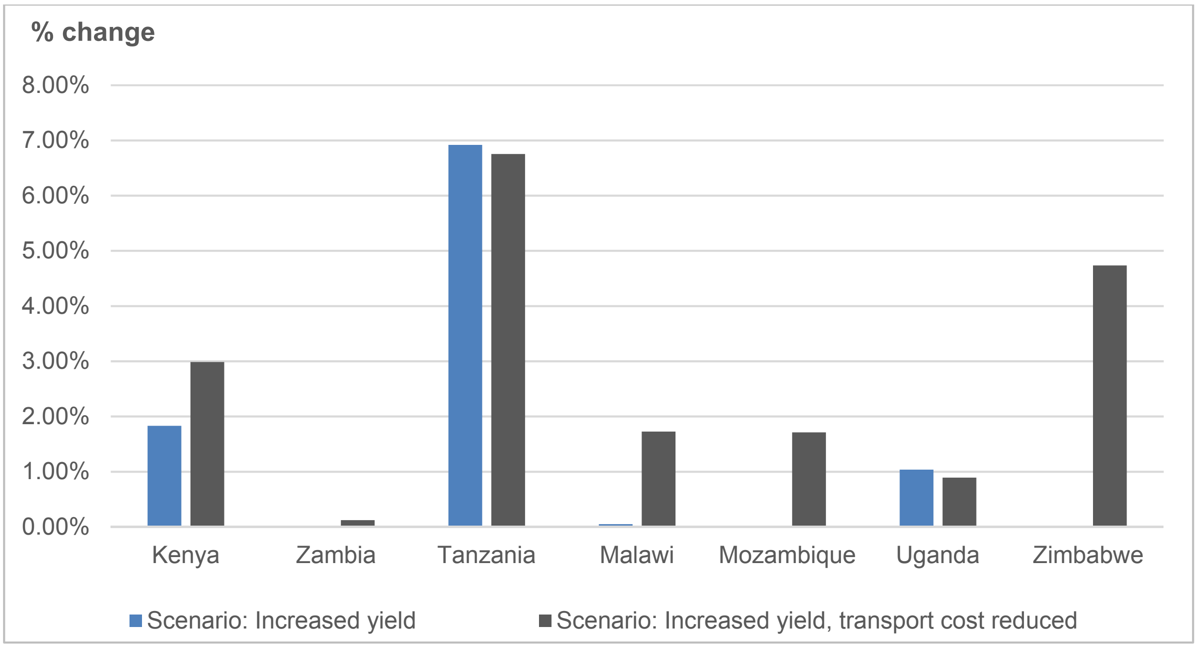

**Figure 5.17: Percentage change in per capita maize consumption in other countries across ESA in 2025 – reduced transportation rates scenario vs. baseline**

While the benefits to the rest of the region are important, the domestic impacts associated with the productivity gains in Tanzania will be the most important consideration for Tanzanian policy makers. Figure 5.18 illustrates such impacts at aggregate level, through the total gross revenue[9] from maize production, as well as the total cost[10] of maize consumed in Tanzania. The figure presents the percentage change in both these measures relative to the baseline in 2025. It is clear that the total revenue from maize production declines in both scenarios, as the reduction in price more than offsets increased output volumes. At the same time, the revenue is generated from a smaller area under cultivation, which leaves producers with the opportunity to generate additional revenue from alternative crops or activities. The cost of maize consumption to consumers at a national level is also reduced in both scenarios and this benefit to consumers outweighs the reduction in producer revenue. Under the scenario where the cost of trade is reduced however, the loss in producer revenue arising from lower prices is minimized. The difference between gains to consumers and the reduction in producer revenue is larger in this scenario, implying that it represents the optimal total societal gain.

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[9] Gross revenue is calculated as total maize production, multiplied by the producer price

[10] The total cost of maize consumption is measured at producer level and represents total national consumption multiplied by the producer price

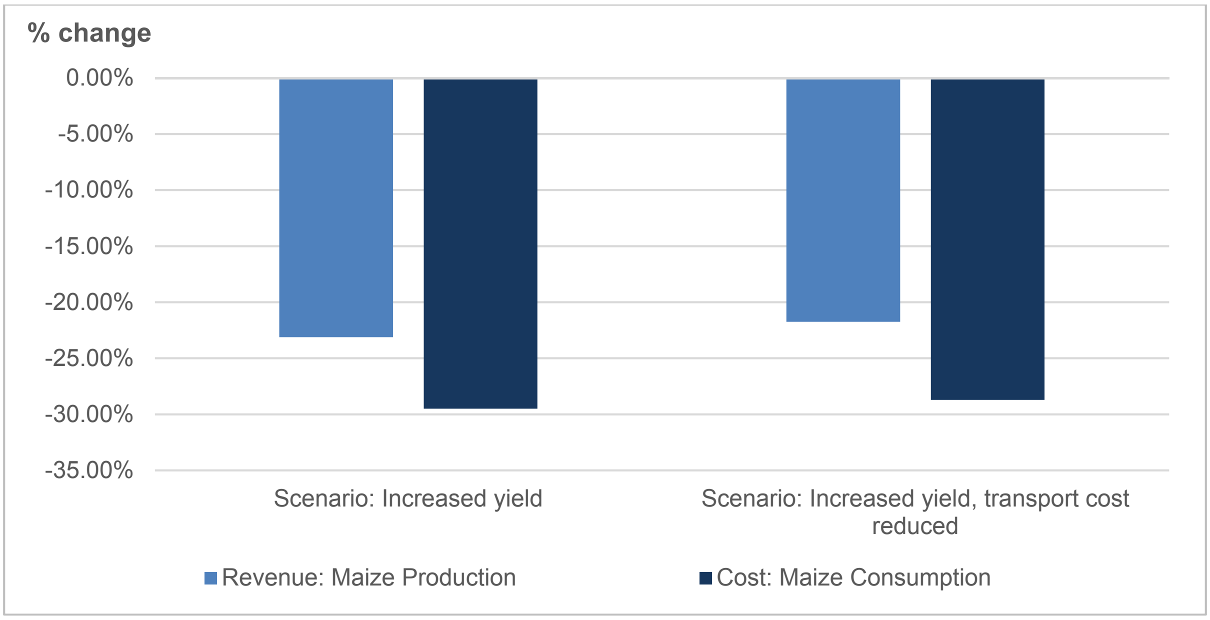

**Figure 5.18: Domestic impacts of different scenarios in relative to the baseline in Tanzania - 2025**

### 5.2.4 Concluding remarks on productivity gains

Despite the well documented benefits of productivity gains in agriculture, the price impacts associated with such gains have not received a lot of attention. Within a traditional price linkage model, productivity gains would have no impact on domestic prices due to the assumption of infinitely elastic export demand. This stands in direct contrast however to the experience in Zambia, where increased output shifted prices from import parity to export parity levels, resulting in a significant decline relative to the rest of the region.

In light of the objectives outlined in the Malabo declaration on accelerated agricultural productivity, the model specified in Chapter 4 was used in this section to illustrate the market impact of accelerated productivity gains, both in isolation and when combined with reductions in transportation costs. Within the applied modelling framework, relaxation of the assumption related to perfectly elastic export demand allowed quantification of the food security benefits attained through lower domestic prices. The impact was illustrated through an alternative scenario of accelerated yield growth in Tanzania, which cultivates the largest area to maize of all the individual countries included in the model. Combined with the substantial yield gap that remains relative to the climatic suitability for maize production, this would suggest that it possesses significant potential to increase maize production and, similar to Zambia in Southern Africa, it could become a consistent exporter in the East African region.

An outward shift of the Tanzanian supply curve as a result of improved yields was shown to cause a significant decline in domestic maize prices, which more than offsets increased output levels and therefore reduces the revenue earned from maize production. The national output is however increased despite a reduction in area cultivated, allowing producers to diversify and generate additional revenue from alternative crops. Reductions in transportation costs were shown to lessen the price impact of increased production, thereby reducing the loss in producer revenue.

The reduction in prices yielded a positive impact for consumers, decreasing the total expenditure on maize consumption at a national level by almost 30%. Such a reduction implies a significant improvement in domestic food security. While lower domestic prices alone was insufficient to initiate trade beyond the East African region, an additional scenario related to infrastructural investment to reduce the cost of transportation initiated exports into Southern African countries, such as Zambia, Malawi and Mozambique. This resulted in wider benefits to the region from the productivity gains achieved in Tanzania and, in line with the objectives of the Malabo declaration, resulted in increased intra-regional trade-flows.

Apart from the quantification of market impacts related to improved productivity in Tanzanian maize production, the simulations served to illustrate the usefulness of the specified model when applied to alternative future outcomes in the ESA region. Its applicability to real world scenarios, which it was shown to simulate plausibly, makes it a useful tool to support decision making as the region strives to reach the goals outlined in the Malabo declaration.

## 5.3 Conclusions

Chapter 5 touched on two important objectives outlined in the Malabo Declaration – firstly the goal of tripling intra-regional trade in Africa and secondly the goal of doubling agricultural productivity growth. In providing a short and long-term application of the modelling structure specified in Chapter 4, it provides empirical evidence to support policy makers who continue to be challenged by the need to balance short-term food security objectives with the long-term goal of sustained and accelerated productivity growth. A lack of trust in market based factors has reinforced the perceived need to react to short run volatility, thus this chapter provides evidence of both the long and short-term impacts of such reactions as opposed to allowing market based factors to work.

Byerlee *et al.* (2006) were clear that interventions to meet short run policy objectives should not undermine long-run market development. However, despite the well-researched benefits of increased intra-regional trade (Morrison & Saris, 2016; Haggblade *et al*., 2008), the frequency of trade continues to be reduced by the discretionary application of trade policies. Such interventions, applied with the stated goal of stabilizing prices in the short run, weaken market incentives and has tended to discourage investment that could expand output and improve market access (Dorosh *et al*., 2009; Byerlee *et al*., 2006).

Globally, findings by Bouet and Laborde (2010), as well as Mitra and Josling (2009) highlight a net welfare loss from export control policies. Simulating the impact of imposing export controls in Zambia during a period of drought induced production shortfalls in the region was in line with global findings. While export controls achieved the desired goal of reducing prices for domestic consumers, this was achieved at the expense of producers, who lose the market induced price increase that would offset some of the reduction in output if trade was allowed to flow freely. As a result, the area under maize production in the years following the policy application in Zambia was reduced. This confirmed the reduced investment and consequent lack of production growth arising from the discretionary application of such policies that is constantly referred to in literature related to the subject. Going one step further however, the impacts of the policy application was also quantified in neighbouring countries, where prices increased as a result of reduced imports. As a result, consumption in these countries also declined, but in future years, production expanded in response to higher prices. Thus, as a result of applying export controls to keep prices at tolerable levels in the short term, the share of regional production occurring in Zambia was reduced in following years.

As an alternative to such short run responses, Dorosh *et al.* (2009), Mitra and Josling (2009) as well as Haggblade *et al.* (2008) all point to the benefits of prioritizing expanded production and long-term productivity growth. As such, the model was also applied to a long term alternative scenario of accelerated productivity growth in Tanzania. Relaxation of the perfectly elastic export demand assumption allowed quantification of the food security benefits attainable from reduced prices in a scenario where Tanzanian maize production increased by almost 20% relative to the baseline. At the same time, a reduction in producer revenue was noted given that, for an inelastic product such as maize, price reductions more than offset increased output volumes. Production did however occur on a smaller total area, implying a possibility for crop diversification and additional revenue from alternative products.

The reduction in consumer expenditure on maize, despite increased volumes consumed, outweighed the loss in producer revenue in the scenario of accelerated long-term productivity growth. This is in contrast to the short-term scenario, where the policy was also shown to redistribute welfare from producers to consumers, but the producer loss far outweighed the benefit to consumers. The reduction in absolute price levels under the scenario of accelerated productivity growth will further reduce the necessity to react to year on year volatility, as volatility around a almost 30% lower average annual price level will be less problematic for consumers. Supporting findings by Jensen and Sandrey (2015), it was shown that the maximum benefit can be attained from accelerated productivity growth when it is accompanied by investment that reduces transportation costs and fosters an environment where intra-regional trade is encouraged and simplified.

Ultimately, governments are concerned with three broad policy objectives: increased productivity to expand production and promote income growth, long run development of markets to enhance efficient resource allocation and protection of the poor and vulnerable from transitionary impacts (Byerlee *et al*., 2006). This cannot be achieved when the last objective overshadows the former two and hence, any policy action aimed at shielding the poor from price increases must be implemented in a predictable, rules based manner that minimizes market distortions. Policies should foster the use of market based instruments and targeted safety nets that aid in managing risk of adverse market outcomes and increases output in the long run.

The management of food price risks and instability should be viewed as part of a holistic strategy to develop food marketing systems that foster broad-based economic growth, poverty reduction and food security. To achieve such goals, improved crop forecasting and market information systems are critical as support to private and public-sector decision makers. The model specified in Chapter 4 and applied to relevant issues and scenarios in Chapter 5 provides an additional tool that can be applied in support of making such decisions, which will remain critical as the region moves towards the targets outlined in the Malabo declaration.

# 6. SUMMARY AND CONCLUSIONS

Despite the progress of the past decade, Africa remains the most food insecure region in the world (United Nations *et al*., 2015). Along with the reduction of poverty and improvement of rural livelihoods, the need to overcome this persistent food insecurity is one of the fundamental factors underpinning the prioritisation of the agricultural sector in the African development agenda. If the African Union's vision for a vibrant and sustainable agricultural sector that eliminates hunger in Africa by 2025 is to be achieved, efficient policies that enable and promote growth in the sector is vital.

As the core food staple in ESA, many of the policies emanating from commitments to reduce extreme poverty and hunger have been applied in the maize subsector. Interventions in maize markets, such as trade policies or strategic food reserves backed by government buying programs influence multitudes of small scale producers that earn a living in the sector, whilst also impacting on the food security of consumers. Historically however, such interventions have been applied in a highly discretionary and often unpredictable manner. Governments have lacked confidence in market based responses from private sector, instead acting to curb volatility. However, inconsistent application has often been to the detriment of investment required to achieve long term goals.

Despite the political focus on reducing volatility, food security also relates to affordability and with few exceptions, maize prices in ESA remain high relative to the rest of the world. Given the substantial budgetary allocation to agricultural policies, the success of the different programs in achieving the long term productivity gains required to reduce prices in the region has been questioned (Mason & Myers, 2013; Jayne, 2012; Jayne & Tschirley, 2009). Amidst the challenge of balancing short-term food security objectives with longer term goals of sustained productivity gains, an undisputed need for forward looking policy analysis has emerged. Such analysis can evaluate policy options and alternative future outcomes prior to implementation, guiding decision making as the region strives to eliminate hunger by 2025.

Models used for forward looking simulations will always be simplifications of reality, but in many instances the structure of these models fail to represent the complexities of agricultural markets sufficiently, which limits their predictive power. This is particularly true in the African context, where transmission from world prices into domestic markets is infrequent and analysis presented in Chapter 2 of this study points to significant non-linearities in price transmission between different markets in the region. Evaluation of different regimes defined by trade volumes, as well as trade policy application point to significant differences in long term price transmission and short-term adjustment rates across regimes. This represents a fundamental mismatch between true price formation in the region and the linear price transmission from global markets that is typically imposed in partial equilibrium simulation models.

By simulating the region wide impact of short term export controls in Zambia, as well as long term productivity gains in Tanzania, this study provides empirical evidence in support of the debate on long and short-term impacts of different policies and alternative future scenarios. Having shown that price transmission patterns in the region are subject to changes across different regimes defined by trade volumes and policy application, the modelling framework accounts for these complex market linkages and regime switches to provide credible scenario simulations. By linking markets through a system of bilateral trade equations as opposed to direct price linkage, price relationships between markets are allowed to switch as trade patterns change over time. Thus, regional prices influence relevant trade partners without losing the domestic supply and demand impact on price dynamics. The study therefore provides a simulation model structure that narrows the gap between knowledge on price formation derived from *ex-post* price transmission analysis and the simplified structure typically assumed in existing simulation models of the region.

Across the different modelling frameworks applied for policy analysis, differences in the structure of trade-flow incorporation and price linkage methodologies are derived from the assumptions related to product homogeneity and spatial explicitness. The spatial equilibrium approach associated with traditional price linkage specifications assumes perfect homogeneity, whereas the so called Armington approach differentiates products based on country of origin, implying that the law of one price is no longer required to hold. The approach presented in this study is derived from the spatial equilibrium approach, which is more successful in replicating historically volatile trade volumes than the Armington specification. Importantly, the assumption of infinitely elastic trade parameters associated with its traditional incorporation in partial equilibrium models through direct price linkage is relaxed. Factors underpinning the need for finite elasticities include the time required to exploit arbitrage conditions, policy implementation, infrastructural restraints, imperfect information and agent expectations – all of which are particularly relevant in the ESA region.

Trade flow equations were specified bilaterally based on price differences between the relevant countries. The introduction of a threshold in the arbitrage correcting parameter however allowed for a quicker adjustment to equilibrium between markets at higher trade volumes. This allows the model to replicate the findings of the price transmission analysis, which indicated that trade volumes influence the rate of price transmission between markets. It also allows the existing price transmission to be reduced when trade limiting policies are applied. Domestic prices are derived from the equilibrium of total supply and total demand in each country, which includes both domestically produced and traded products. The bilateral trade flow specification allows for the influence of multiple trade partners on domestic prices in any one country, with price transmission being the strongest from markets where export volumes are the highest. In essence, pricing in the model is allowed to switch not only between import parity, export parity and autarkic regimes, but also between different markets as trade fluctuates. By implication, the specification also allows for stronger future price transmission between markets where it is historically weak if trade is initiated from very low levels. This is not the case if a pre-estimated price transmission is imposed through direct price linkage. Considering the extent to which Zambia's evolution from a deficit to a surplus producer influenced regional trade and pricing dynamics over the past decade, the ability to capture changes in future pricing dynamics if a similar situation unfolds in another country is vital.

The short length of the historic price series, particularly at annual frequency, necessitated the use of synthetic parameters in the trade-flow equations. Furthermore, in light of the focus of this study on the trade-price solution, the parameters for domestic supply and demand estimates were also applied synthetically based on a combination of existing literature, economic theory and analyst judgement. While the use of synthetic parameters is frequently applied in both partial equilibrium and particularly general equilibrium models when data is of poor quality or not available (Van Tongeren *et al.,* 2001), it complicates model validation. As no single statistical test can be applied to render a complete synthetic simulation model valid or not, a combination of tests, including historic in sample validation and future projections, were applied before drawing conclusions on model validation.

Firstly, the proposed trade linked model was applied to simulate historic price levels from 2013 to 2016 after accounting for production fluctuations and world price volatility. Using a combination of tests associated with goodness of fit, including the root mean square error (RMSE), the mean absolute error (MAE), the modified index of agreement (MD) and the modified Nash-Sutcliffe efficiency (mNSE), the proposed model was compared to a traditional price linkage specification. Across all four indicators, the trade-linked model outperformed the traditional price linkage approach by a significant margin, reflecting a lower RMSE and MAE accompanied by a higher MD and nMSE.

Secondly, both models were applied to simulate demand, supply, trade and prices over a ten-year horizon. Evaluation of such projections is however subjective in nature, as it relates to the future. Both the proposed trade-linkage model and the traditional price linkage approach generated a plausible baseline outlook based on the same set of exogenously defined assumptions, with the key difference evident in trade projections. The proposed trade-linked model generated an outlook where trade from outside the region is less than is the case in a traditional price linkage approach, which seemed more plausible and in line with historic observations. In evaluating the different models' sensitivity to international price movements and domestic supply reductions, the trade linked model was found to be very sensitive to domestic factors, whilst only generating small price movements in response to world price fluctuations. Conversely, the traditional price linkage approach yielded larger responses to world price fluctuations and no price response from the domestic supply shock. This stands in direct contrast to literature where consensus has emerged that domestic factors, rather than world price fluctuations, have been responsible for the bulk of volatility in the region's maize prices.

Thirdly, in light of the notorious volatility in agricultural markets arising from the dependence on changeable weather conditions, the ability of the two different modelling structures to replicate historic volatility was also considered. Volatility in domestic yield levels and world prices over the past decade were applied to the baseline projection, showing the proposed trade-linked model to be more efficient at replicating historic volatility than the price linkage approach. This remained true when the comparison was repeated with an altered model structure where the US yellow maize price originally used as world reference price is replaced with the South African white maize price.

Lastly, in the spirit of Boland (1989), who suggests that models will always remain simplifications of reality and should ultimately be judged on their ability to provide credible answers to the questions that they were designed to address, the proposed model was applied to two different future scenarios. Neither of these would have been simulated credibly through a price linkage approach due to the implied lack of price impacts in response to domestic supply and demand fluctuations, which have been shown by literature to be the main drivers of price volatility in the region. The short-term application related to the discretionary implementation of export controls in Zambia in a drought induced domestic supply shortage. The long-term application related to accelerated productivity gains in Tanzania and the associated impact on price levels and trade-flow in the ESA region. In light of the stated objective in the Malabo declaration on accelerated agricultural growth to triple intra-regional trade, it also goes one step further in evaluating the differences in trade generation under an accelerated productivity scenario when the cost of trade is reduced.

The imposition of export controls in Zambia resulted in a net loss to society in the region. Whilst achieving the stated goal of reducing domestic prices for consumers, it was achieved at the expense of producers who lose the market induced price increase that would offset some of the losses associated with reduced output if trade was allowed to occur freely. While the implementation of trade controls also had a negative impact on consumers in neighbouring countries through higher prices, it induced a shift in production in the years following the policy application. In neighbouring countries, area cultivated to maize expanded in response to higher returns, but in Zambia it was reduced.

As an alternative to short term responses such as trade controls, literature points to the benefits of prioritizing long-term productivity gains. As such, an alternative future scenario was simulated where productivity growth is accelerated in Tanzania, the country with the largest area cultivated to maize in the region. Relaxation of the perfectly elastic export demand assumption allowed quantification of the food security benefits attainable from reduced prices in a scenario where Tanzanian maize production increased by more than 20% relative to the baseline. The result is similar to the situation that played out in Zambia over the past decade, where the switch from net importing to net exporting status induced a substantial reduction in prices. In the Tanzanian simulation, the gains to consumers from lower prices were shown to outweigh the loss in producer revenue, resulting in a positive impact on net welfare. The reduction in absolute price levels further reduce the need to react to year on year volatility, as volatility around a 30% lower average annual price level will be less problematic for consumers. The benefit from accelerated productivity growth in Tanzania was maximized when trade costs were reduced, affirming the need for such gains to be accompanied by investment that reduces transportation costs and fosters an environment where intra-regional trade is encouraged and simplified.

Byerlee *et al.* (2006) notes that governments are ultimately concerned with three broad policy objectives: 1) increased productivity to expand production and promote income growth, 2) long run development of markets to enhance efficient resource allocation and 3) protection of the poor and vulnerable from transitionary impacts. Long term policy goals will not be achieved when the latter over shadows the former, but given the timing and reach of impact when short term actions are prioritised, policy makers will continue to be challenged by the need to balance these goals. The policy simulations conducted in this study however provide evidence of the benefit that can be achieved if long term productivity gains are prioritised as opposed to short term reactions to volatility.

As the region moves towards the implementation of the Malabo declaration and strives to eradicate hunger by 2025, this study was valuable in two regards. Firstly, it provided empirical evidence to support the prioritisation of long term productivity gains as opposed to short term reactions to inherently volatile markets. Secondly, it specified and validated a model structure that is a considerable improvement on traditional approaches in terms of capturing the complexities of price formation and trade flow in the region. In doing so, it has provided a tool that can be used for forward looking policy analysis, enabling future support to policy makers prior to implementation.

The focus on maize markets emanated from its association with food security and its consequent prioritisation from a policy perspective. The undoubted relevance of the applied model to maize markets rests on the dominance of intra-regional trade and the differentiation of the product typically consumed in ESA from that traded in the rest of the world. Nonetheless, the model structure presented is replicable for other commodities and regions. Given that trade agreements are increasingly being applied in the bilateral context, the inclusion of spatially explicit features in the partial equilibrium context holds distinct possibilities for trade policy evaluations going forward.

In focusing on maize markets in ESA, the modelling framework presented in this study remains limited by the exclusion of alternative commodities and countries. Increased country coverage will improve the extent of policy evaluation and enable inclusion of growing consumption hubs in West Africa that are not currently considered. This will however also require an expansion of commodity coverage, as the relevance of different commodities change in other parts of the continent.

Even within the existing countries, expansion of the commodity coverage to include substitute products and the associated cross price elasticities, both in terms of production and consumption, would represent a significant improvement in future research. As income levels increase and urbanisation continues, the inclusion of substitute products such as wheat, which often represents a more convenient alternative to consumers in urban hubs will become increasingly relevant. At the same time, the scenario simulation related to accelerated productivity gains indicated that production is increased despite a reduction in area, which allows producers to gain revenue from alternative products. This switch to alternatives and the resulting diversification of agriculture in the region can be simulated more explicitly if the commodity coverage is expanded.

Maize remains the primary food staple and it will continue to be prioritised until food security in the region improves. As diets diversify in future, it will become increasingly relevant as a feed grain, which may lead to the adoption of yellow maize production in the region and increase the integration in global markets. In this regard, the exclusion of livestock from the current modelling framework implies that possible increases in feed use are captured imperfectly. While some price response is included, feed use projections will benefit from the inclusion of livestock production in the modelling framework, which will enable feed use to increase more rapidly when intensive livestock production increases. Nonetheless, the structure presented in this study will allow possible shifts in price transmission patterns in future to be captured through increased trade in the global market.

Africa remains the largest recipient of food aid in the world and with population growth expected to remain rapid over the next ten years, global debates related to Africa's ability to feed itself remain relevant. Despite its clear limitations in terms of geographic and commodity coverage, this study went some way to showing that, in a scenario where stated productivity gains are achieved and combined with sufficient investment in infrastructure in an environment where intra-regional trade is encouraged and simplified, some countries in Africa will indeed be able to provide its core food staple to a growing population at prices comparable to world levels. As it moves towards achieving this vision, the tools provided in this study hold undoubted potential in evaluating policy alternatives and informing decision making, both to public and private sector. Better informed decision making will certainly increase Africa's chances of achieving this dream.

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# APPENDIX 1: UNIT ROOT TESTS ASSOCIATED WITH TRADE DEFINED REGIMES

**Table A1.1: Unit root tests in levels over entire series**

| Country: Market | Model | Lag | Test Statistics | | | Conclusion |
|---|---|---|---|---|---|---|
| | | | ADF | PP | KPSS | |
| **South Africa: SAFEX Randfontein** | Drift | 1 | -2.56 | -2.27 | 1.89** | Non-Stationary |
| | Trend | 1 | -2.18 | -1.97 | 0.32** | Non-Stationary |
| **Zambia: Lusaka** | Drift | 1 | -3.06** | -2.92** | 1.33** | Inconclusive |
| | Trend | 1 | -3.23* | -3.11 | 0.51** | Inconclusive |
| **Zimbabwe: Harare** | Drift | 7 | -3.05** | -3.73** | 0.41* | Inconclusive |
| | Trend | 7 | -3.44* | -4.11** | 0.05 | Stationary |
| **Malawi: Lilongwe** | Drift | 1 | -3.02** | -2.82* | 0.96** | Inconclusive |
| | Trend | 1 | -2.98 | -2.81 | 0.27** | Non-Stationary |
| **Mozambique: Maputo** | Drift | 4 | -2.44 | -2.42 | 1.39** | Non-Stationary |
| | Trend | 4 | -3.04 | -3.14 | 0.16** | Non-Stationary |
| **Mozambique: Tete** | Drift | 2 | -2.97** | -3.06** | 0.75** | Inconclusive |
| | Trend | 2 | -3.12 | -3.14* | 0.14* | Inconclusive |

*** Significant at 5%, * Significant at 10%*

**Table A1.2: Unit root tests in first difference over entire series**

| Country: Market | Model | Lag | Test Statistics | | | Conclusion |
|---|---|---|---|---|---|---|
| | | | ADF | PP | KPSS | |
| **South Africa: SAFEX Randfontein** | Drift | 0 | -9.72** | -9.71** | 0.19 | Stationary |
| | Trend | 0 | -9.83** | -9.81** | 0.06 | Stationary |
| **Zambia: Lusaka** | Drift | 0 | -10.99** | -11.19** | 0.03 | Stationary |
| | Trend | 0 | -10.96** | -11.16** | 0.03 | Stationary |
| **Zimbabwe: Harare** | Drift | 2 | -6.78** | -15.94** | 0.04 | Stationary |
| | Trend | 2 | -6.75** | -15.88** | 0.03 | Stationary |
| **Malawi: Lilongwe** | Drift | 0 | -10.20** | -10.20** | 0.06 | Stationary |
| | Trend | 0 | -10.19** | -10.19** | 0.03 | Stationary |
| **Mozambique: Maputo** | Drift | 0 | -8.99** | -8.89** | 0.04 | Stationary |
| | Trend | 0 | -8.95** | -8.85** | 0.03 | Stationary |
| **Mozambique: Tete** | Drift | 0 | -9.05** | -8.99** | 0.05 | Stationary |
| | Trend | 0 | -9.03** | -8.94** | 0.03 | Stationary |

*** Significant at 5%, * Significant at 10%*

**Table A1.3: Unit root tests in levels below the estimated threshold**

| Price series tested | Trade partner | Model | Threshold | Lag | Test Statistics | | | Conclusion |
|---|---|---|---|---|---|---|---|---|
| | | | | | ADF | PP | KPSS | |
| South Africa: SAFEX Randfontein | Zambia: Lusaka | Drift | 690.3 | 1 | -3.05** | -2.95** | 1.48** | Inconclusive |
| | | Trend | | 1 | -2.83 | -2.91 | 0.27** | Non-Stationary |
| Zambia: Lusaka | South Africa: SAFEX Randfontein | Drift | 690.3 | 1 | -3.45** | -4.25** | 0.98** | Inconclusive |
| | | Trend | | 1 | -3.61** | -4.63** | 0.38** | Inconclusive |
| Zambia: Lusaka | Zimbabwe: Harare | Drift | 221.8 | 1 | -1.85 | -1.95 | 0.85** | Non-Stationary |
| | | Trend | | 1 | -2.76 | -2.87 | 0.09 | Inconclusive |
| Zimbabwe: Harare | Zambia: Lusaka | Drift | 221.8 | 1 | -2.74* | -2.49 | 0.18 | Inconclusive |
| | | Trend | | 1 | -2.64 | -2.43 | 0.12 | Inconclusive |
| South Africa: SAFEX Randfontein | Zimbabwe: Harare | Drift | 5897.8 | 1 | -1.67 | -1.69 | 0.78** | Non-Stationary |
| | | Trend | | 1 | -0.88 | -1.15 | 0.19** | Non-Stationary |
| Zimbabwe: Harare | South Africa: SAFEX Randfontein | Drift | 5897.8 | 1 | -1.68 | -1.32 | 2.01** | Non-Stationary |
| | | Trend | | 1 | -1.40 | -3.28* | 0.45** | Inconclusive |
| Malawi: Lilongwe | Mozambique: Tete | Drift | 31.0 | 1 | -2.81* | -3.70** | 0.46** | Inconclusive |
| | | Trend | | 1 | -3.43* | -3.88** | 0.05 | Stationary |
| Mozambique: Tete | Malawi: Lilongwe | Drift | 31.0 | 2 | -2.25 | -2.91** | 0.62** | Inconclusive |
| | | Trend | | 2 | -2.96 | -3.73** | 0.05 | Inconclusive |
| South Africa: SAFEX Randfontein | Mozambique: Maputo | Drift | 10381.5 | 1 | -2.77* | -2.34 | 1.64** | Inconclusive |
| | | Trend | | 1 | -2.43 | -2.01 | 0.27** | Non-Stationary |
| Mozambique: Maputo | South Africa: SAFEX Randfontein | Drift | 10381.5 | 1 | -2.11 | -2.40 | 3.17** | Inconclusive |
| | | Trend | | 1 | -3.18* | -3.85** | 0.34** | Inconclusive |
| Zambia: Lusaka | Malawi: Lilongwe | Drift | 430.8 | 1 | -3.40** | -3.49** | 0.36* | Inconclusive |
| | | Trend | | 1 | -3.42* | -3.49** | 0.33** | Inconclusive |
| Malawi: Lilongwe | Zambia: Lusaka | Drift | 430.8 | 2 | -2.52 | -2.44 | 0.58** | Non-Stationary |
| | | Trend | | 2 | -2.48 | -2.42 | 0.29** | Non-Stationary |

*** Significant at 5%, * Significant at 10%*

**Table A1.4: Unit root tests in levels above the estimated threshold**

| Price series tested | Trade partner | Model | Threshold | Lag | Test statistics | | | Conclusion |
|---|---|---|---|---|---|---|---|---|
| | | | | | ADF | PP | KPSS | |
| South Africa: SAFEX Randfontein | Zambia: Lusaka | Drift | 690.3 | 1 | -2.71* | -3.58** | 0.37* | Inconclusive |
| | | Trend | | 1 | -2.09 | -2.85 | 0.18** | Non-Stationary |
| Zambia: Lusaka | South Africa: SAFEX Randfontein | Drift | 690.3 | 1 | -1.45 | -1.09 | 0.76** | Non-Stationary |
| | | Trend | | 1 | 0.42 | -2.05 | 0.14* | Non-Stationary |
| Zambia: Lusaka | Zimbabwe: Harare | Drift | 221.8 | 1 | -2.70* | -2.93** | 1.02** | Inconclusive |
| | | Trend | | 1 | -2.78 | -3.12 | 0.33** | Non-Stationary |
| Zimbabwe: Harare | Zambia: Lusaka | Drift | 221.8 | 2 | -2.11 | -3.45* | 1.58** | Inconclusive |
| | | Trend | | 2 | -2.91** | -4.81** | 0.11 | Stationary |
| South Africa: SAFEX Randfontein | Zimbabwe: Harare | Drift | 5897.8 | 1 | -2.30 | -2.22 | 1.32 | Non-Stationary |
| | | Trend | | 1 | -2.04 | -2.25 | 0.25 | Non-Stationary |
| Zimbabwe: Harare | South Africa: SAFEX Randfontein | Drift | 5897.8 | 1 | -2.80* | -3.85** | 0.60** | Inconclusive |
| | | Trend | | 1 | -2.83 | -4.08** | 0.12 | Inconclusive |
| Malawi: Lilongwe | Mozambique: Tete | Drift | 31.0 | 1 | -3.04** | -3.08** | 0.82** | Inconclusive |
| | | Trend | | 1 | -3.05 | -3.17* | 0.26** | Inconclusive |
| Mozambique: Tete | Malawi: Lilongwe | Drift | 31.0 | 1 | -3.12** | -3.18** | 0.66** | Inconclusive |
| | | Trend | | 1 | -3.15 | -3.22* | 0.18** | Inconclusive |
| South Africa: SAFEX Randfontein | Mozambique: Maputo | Drift | 10381.5 | 1 | -1.94 | -2.23 | 0.50** | Non-Stationary |
| | | Trend | | 1 | -1.45 | -2.00 | 0.18** | Non-Stationary |
| Mozambique: Maputo | South Africa: SAFEX Randfontein | Drift | 10381.5 | 1 | -2.33 | -2.51 | 0.49** | Non-Stationary |
| | | Trend | | 1 | -1.89 | -2.24 | 0.23** | Non-Stationary |
| Zambia: Lusaka | Malawi: Lilongwe | Drift | 430.8 | 2 | -2.41 | -3.29** | 0.36* | Inconclusive |
| | | Trend | | 2 | -2.25 | -3.07 | 0.06 | Inconclusive |
| Malawi: Lilongwe | Zambia: Lusaka | Drift | 430.8 | 1 | -2.90* | -2.97** | 0.29 | Stationary |
| | | Trend | | 1 | -2.52 | -2.71 | 0.17** | Non-Stationary |

*** Significant at 5%, * Significant at 10%*

**Table A1.5: Unit root tests in first difference below the estimated threshold**

| Price series tested | Trade partner | Model | Threshold | Lag | Test Statistics | | | Conclusion |
|---|---|---|---|---|---|---|---|---|
| | | | | | ADF | PP | KPSS | |
| South Africa: SAFEX Randfontein | Zambia: Lusaka | Drift | 690.3 | 3 | -5.73** | -12.57** | 0.17 | Stationary |
| | | Trend | | 3 | -6.03** | -12.87** | 0.05 | Stationary |
| Zambia: Lusaka | South Africa: SAFEX Randfontein | Drift | 690.3 | 1 | -10.13** | -15.64** | 0.03 | Stationary |
| | | Trend | | 1 | -10.11** | -15.60** | 0.02 | Stationary |
| Zambia: Lusaka | Zimbabwe: Harare | Drift | 221.8 | 0 | -5.18** | -5.20** | 0.05 | Stationary |
| | | Trend | | 0 | -5.06** | -5.08** | 0.05 | Stationary |
| Zimbabwe: Harare | Zambia: Lusaka | Drift | 221.8 | 0 | -4.70** | -4.70** | 0.06 | Stationary |
| | | Trend | | 0 | -4.62** | -4.61** | 0.04 | Stationary |
| South Africa: SAFEX Randfontein | Zimbabwe: Harare | Drift | 5897.8 | 0 | -7.30** | -7.31** | 0.25 | Stationary |
| | | Trend | | 0 | -7.60** | -7.58** | 0.13* | Inconclusive |
| Zimbabwe: Harare | South Africa: SAFEX Randfontein | Drift | 5897.8 | 0 | -10.05** | -10.31** | 0.15 | Stationary |
| | | Trend | | 0 | -9.95** | -10.52** | 0.11 | Stationary |
| Malawi: Lilongwe | Mozambique: Tete | Drift | 31.0 | 0 | -7.20** | -7.67** | 0.05 | Stationary |
| | | Trend | | 0 | -7.07** | -7.52** | 0.03 | Stationary |
| Mozambique: Tete | Malawi: Lilongwe | Drift | 31.0 | 0 | -6.58** | -7.20** | 0.04 | Stationary |
| | | Trend | | 0 | -6.49** | -7.13** | 0.03 | Stationary |
| South Africa: SAFEX Randfontein | Mozambique: Maputo | Drift | 10381.5 | 0 | -8.70** | -8.66** | 0.17 | Stationary |
| | | Trend | | 0 | -8.83** | -8.79** | 0.07 | Stationary |
| Mozambique: Maputo | South Africa: SAFEX Randfontein | Drift | 10381.5 | 0 | -12.54** | -13.13** | 0.03 | Stationary |
| | | Trend | | 0 | -12.48** | -13.06** | 0.02 | Stationary |
| Zambia: Lusaka | Malawi: Lilongwe | Drift | 430.8 | 0 | -9.97** | -10.07** | 0.03 | Stationary |
| | | Trend | | 0 | -9.91** | -10.01** | 0.03 | Stationary |
| Malawi: Lilongwe | Zambia: Lusaka | Drift | 430.8 | 1 | -6.72** | -7.48** | 0.06 | Stationary |
| | | Trend | | 1 | -6.71** | -7.45** | 0.04 | Stationary |

*** Significant at 5%, * Significant at 10%*

**Table A1.6: Unit root tests in first difference above the estimated threshold**

| Price series tested | Trade partner | Model | Threshold | Lag | Test statistics | | | Conclusion |
|---|---|---|---|---|---|---|---|---|
| | | | | | ADF | PP | KPSS | |
| South Africa: SAFEX Randfontein | Zambia: Lusaka | Drift | 690.3 | 0 | -4.24** | -5.63** | 0.18 | Stationary |
| | | Trend | | 0 | -5.59** | -5.72** | 0.03 | Stationary |
| Zambia: Lusaka | South Africa: SAFEX Randfontein | Drift | 690.3 | 0 | -5.38** | -5.15** | 0.16 | Stationary |
| | | Trend | | 0 | -5.70** | -5.60** | 0.12* | Inconclusive |
| Zambia: Lusaka | Zimbabwe: Harare | Drift | 221.8 | 0 | -11.51** | -11.71** | 0.04 | Stationary |
| | | Trend | | 0 | -11.46** | -11.68** | 0.03 | Stationary |
| Zimbabwe: Harare | Zambia: Lusaka | Drift | 221.8 | 2 | -7.65** | -14.93** | 0.04 | Stationary |
| | | Trend | | 2 | -7.61** | -14.84** | 0.03 | Stationary |
| South Africa: SAFEX Randfontein | Zimbabwe: Harare | Drift | 5897.8 | 0 | -8.31** | -8.30** | 0.11 | Stationary |
| | | Trend | | 0 | -8.41** | -8.40** | 0.05 | Stationary |
| Zimbabwe: Harare | South Africa: SAFEX Randfontein | Drift | 5897.8 | 1 | -7.77** | -11.87** | 0.05 | Stationary |
| | | Trend | | 1 | -7.73** | -11.82** | 0.03 | Stationary |
| Malawi: Lilongwe | Mozambique: Tete | Drift | 31.0 | 0 | -10.38** | -10.82** | 0.04 | Stationary |
| | | Trend | | 0 | -10.35** | -10.81** | 0.02 | Stationary |
| Mozambique: Tete | Malawi: Lilongwe | Drift | 31.0 | 0 | -9.35** | -9.37** | 0.05 | Stationary |
| | | Trend | | 0 | -9.31** | -9.33** | 0.03 | Stationary |
| South Africa: SAFEX Randfontein | Mozambique: Maputo | Drift | 10381.5 | 0 | -5.28** | -5.36** | 0.14 | Stationary |
| | | Trend | | 0 | -5.45** | -5.72** | 0.04 | Stationary |
| Mozambique: Maputo | South Africa: SAFEX Randfontein | Drift | 10381.5 | 0 | -5.92** | -6.52** | 0.11 | Stationary |
| | | Trend | | 0 | -6.08** | -7.60** | 0.03 | Stationary |
| Zambia: Lusaka | Malawi: Lilongwe | Drift | 430.8 | 0 | -5.03** | -5.09** | 0.12 | Stationary |
| | | Trend | | 0 | -5.05** | -5.11** | 0.05 | Stationary |
| Malawi: Lilongwe | Zambia: Lusaka | Drift | 430.8 | 0 | -6.35** | -6.69** | 0.10 | Stationary |
| | | Trend | | 0 | -6.51** | -7.05** | 0.03 | Stationary |

*** Significant at 5%, * Significant at 10%*

# APPENDIX 2: UNIT ROOT TESTS ASSOCIATED WITH POLICY DEFINED REGIMES

**Table A2.1: Unit root tests in levels**

| | **Model** | **Test statistics** | | | **Conclusion** |
|---|---|---|---|---|---|
| | | **ADF** | **PP** | **KPSS** | |
| **Regime 1: Open trade “Open”** | | | | | |
| **South Africa: SAFEX Randfontein** | Drift | -2.73* | -2.53 | 0.20 | Inconclusive |
| | Trend | -2.68 | -2.55 | 0.08 | Inconclusive |
| **Zambia: Lusaka** | Drift | -3.06** | -2.77* | 0.13 | Stationary |
| | Trend | -3.06 | -2.74 | 0.13* | Non-stationary |
| **Zimbabwe: Harare** | Drift | -1.45 | -1.36 | 1.0** | Non-stationary |
| | Trend | -2.46 | -2.57 | 0.24** | Non-stationary |
| **Regime 2: Trade controls “Closed”** | | | | | |
| **South Africa: SAFEX Randfontein** | Drift | -1.84 | -1.85 | 0.79** | Non-stationary |
| | Trend | -2.21 | -2.57 | 0.08 | Inconclusive |
| **Zambia: Lusaka** | Drift | -3.62** | -2.61* | 0.12 | Stationary |
| | Trend | -3.48* | -2.51 | 0.12 | Inconclusive |
| **Zimbabwe: Harare** | Drift | -1.83 | -2.65* | 0.49** | Inconclusive |
| | Trend | -1.90 | -3.27* | 0.15** | Inconclusive |

*** Significant at 5%, * Significant at 10%*

**Table A2.2: Unit root tests in first difference**

| | **Model** | **Test statistics** | | | **Conclusion** |
|---|---|---|---|---|---|
| | | **ADF** | **PP** | **KPSS** | |
| **Regime 1: Open trade “Open”** | | | | | |
| **South Africa: SAFEX Randfontein** | Drift | -10.20** | -10.19** | 0.10 | Stationary |
| | Trend | -10.16** | -10.14** | 0.09 | Stationary |
| **Zambia: Lusaka** | Drift | -6.23** | -7.66** | 0.06 | Stationary |
| | Trend | -6.23** | -7.62** | 0.04 | Stationary |
| **Zimbabwe: Harare** | Drift | -10.34** | -10.52** | 0.06 | Stationary |
| | Trend | -10.28** | -10.45** | 0.06 | Stationary |
| **Regime 2: Trade controls “Closed”** | | | | | |
| **South Africa: SAFEX Randfontein** | Drift | -7.99** | -7.99** | 0.11 | Stationary |
| | Trend | -8.02** | -9.03** | 0.06 | Stationary |
| **Zambia: Lusaka** | Drift | -3.84** | -4.32** | 0.08 | Stationary |
| | Trend | -3.90** | -4.28** | 0.03 | Stationary |
| **Zimbabwe: Harare** | Drift | -6.87** | -10.56** | 0.07 | Stationary |
| | Trend | -6.83** | -10.50** | 0.05 | Stationary |

*** Significant at 5%, * Significant at 10%*

**Table A2.3: Periods defined by open and restricted trade regimes (January 2005-October 2016)**

| Period | Regime |
|---|---|
| January 2005 – February 2005 | Open trade |
| March 2005 – July 2006 | Export controls |
| August 2006 – April 2008 | Open trade |
| May 2008 – July 2009 | Export controls |
| August 2009 – November 2012 | Open trade |
| December 2012 – April 2013 | Export controls |
| May 2013 – August 2013 | Open trade |
| September 2013 – April 2014 | Export controls |
| May 2014 – March 2016 | Open trade |
| April 2016 – October 2016 (end of series) | Export controls |

*Source: Compiled from Porteous, 2012, popular media and personal communication*

# APPENDIX 3: TRADE PARAMETER ASSUMPTIONS

**Table A3.1: Assumptions on export parameters**

| Exporter | Importer | $\boldsymbol{m_{ij}}$ | $\boldsymbol{k_{ij}}$ | $\boldsymbol{l_{ij}}$ | $\boldsymbol{\beta_1}$ | $\boldsymbol{\beta_2}$ | $\boldsymbol{\beta_3}$ |
|---|---|---|---|---|---|---|---|
| Kenya: Eldoret | Malawi: Lilongwe | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Kenya: Eldoret | Mozambique: Maputo | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Kenya: Eldoret | South Africa: Randfontein | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Kenya: Eldoret | Tanzania: Arusha | 60 | 0 | NA | 0.35 | 3.50 | NA |
| Kenya: Eldoret | Uganda: Kampala | 10 | 10 | NA | 0.25 | 2.50 | NA |
| Kenya: Eldoret | Zambia: Lusaka | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Kenya: Eldoret | Zimbabwe: Harare | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Kenya: Eldoret | Other | 100 | -50 | NA | 0.25 | 2.50 | NA |
| | | | | | | | |
| Malawi: Lilongwe | Kenya: Nairobi | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Malawi: Lilongwe | Mozambique: Nampula | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Malawi: Lilongwe | South Africa: Randfontein | 40 | 10 | NA | 0.30 | 3.00 | NA |
| Malawi: Mzuzu | Tanzania: Mbeya | 60 | 0 | NA | 1.60 | 8.00 | NA |
| Malawi: Lilongwe | Uganda: Kampala | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Malawi: Lilongwe | Zambia: Lusaka | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Malawi: Lilongwe | Zimbabwe: Harare | 20 | 10 | NA | 0.65 | 6.50 | NA |
| Malawi: Lilongwe | Other | 100 | -50 | NA | 0.25 | 2.50 | NA |
| | | | | | | | |
| Mozambique: Nampula | Kenya: Nairobi | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Mozambique: Tete | Malawi: Lilongwe | 50 | 0 | NA | 0.65 | 3.25 | NA |
| Mozambique: Maputo | South Africa: Randfontein | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Mozambique: Nampula | Tanzania: Dar es Salaam | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Mozambique: Nampula | Uganda: Kampala | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Mozambique: Nampula | Zambia: Lusaka | 30 | 10 | NA | 0.25 | 2.50 | NA |
| Mozambique: Nampula | Zimbabwe: Harare | 20 | -20 | NA | 0.15 | 1.50 | NA |
| Mozambique: Nampula | Other | 40 | -10 | NA | 0.25 | 2.50 | NA |
| | | | | | | | |
| South Africa: Randfontein | Kenya: Nairobi | 50 | 0 | NA | 0.79 | 3.95 | NA |
| South Africa: Randfontein | Malawi: Lilongwe | 20 | 10 | NA | 0.08 | 0.79 | NA |
| South Africa: Randfontein | Mozambique: Maputo | 0 | 80 | 150 | 0.89 | 1.78 | 3.56 |
| South Africa: Randfontein | Tanzania: Dar Es Salaam | 50 | 20 | NA | 0.06 | 0.30 | NA |
| South Africa: Randfontein | Uganda: Kampala | 50 | 20 | NA | 0.25 | 2.50 | NA |
| South Africa: Randfontein | Zambia: Lusaka | 50 | -15 | NA | 0.56 | 5.60 | NA |
| South Africa: Randfontein | Zimbabwe: Harare | 30 | 0 | NA | 1.80 | 9.00 | NA |
| South Africa: Randfontein | Other | 80 | 60 | NA | 5.45 | 32.7 | NA |
| | | | | | | | |
| Tanzania: Arusha | Kenya: Nairobi | 20 | 10 | 40 | 0.30 | 2.40 | 7.20 |
| Tanzania: Mbeya | Malawi: Lilongwe | 50 | -10 | NA | 0.09 | 1.28 | NA |
| Tanzania: Mbeya | Mozambique: Nampula | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Tanzania: Arusha | South Africa: Randfontein | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Tanzania: Arusha | Uganda: Kampala | 50 | 10 | NA | 0.25 | 2.50 | NA |
| Tanzania: Mbeya | Zambia: Lusaka | 10 | 10 | NA | 0.20 | 1.20 | NA |
| Tanzania: Mbeya | Zimbabwe: Harare | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Tanzania: Arusha | Other | 80 | -20 | NA | 1.25 | 12.5 | NA |
| | | | | | | | |
| Uganda: Kampala | Kenya: Eldoret | 30 | 20 | NA | 1.20 | 8.40 | NA |
| Uganda: Kampala | Malawi: Lilongwe | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Uganda: Kampala | Mozambique: Nampula | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Uganda: Kampala | South Africa: Randfontein | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Uganda: Kampala | Tanzania: Dar es Salaam | 70 | 10 | NA | 0.35 | 3.50 | NA |
| Uganda: Kampala | Zambia: Lusaka | 60 | 20 | NA | 0.65 | 5.16 | NA |

| **Exporter** | **Importer** | $m_{ij}$ | $k_{ij}$ | $l_{ij}$ | $\beta_1$ | $\beta_2$ | $\beta_3$ |
|---|---|---|---|---|---|---|---|
| Uganda: Kampala | Zimbabwe: Harare | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Uganda: Kampala | Other | 200 | -100 | NA | 0.65 | 6.50 | NA |
| | | | | | | | |
| Zambia: Lusaka | Kenya: Nairobi | 50 | -20 | NA | 0.25 | 2.50 | NA |
| Zambia: Lusaka | Malawi: Lilongwe | 30 | -15 | NA | 0.47 | 2.35 | NA |
| Zambia: Lusaka | Mozambique: Nampula | 50 | -10 | NA | 0.25 | 1.25 | NA |
| Zambia: Choma | South Africa: Randfontein | 150 | -100 | NA | 0.55 | 2.73 | NA |
| Zambia: Lusaka | Tanzania: Mbeya | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zambia: Lusaka | Uganda: Kampala | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zambia: Lusaka | Zimbabwe: Harare | 20 | 0 | 10 | 1.20 | 12.0 | 24.0 |
| Zambia: Lusaka | Other | 70 | -20 | NA | 0.45 | 4.50 | NA |
| | | | | | | | |
| Zimbabwe: Harare | Kenya: Nairobi | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zimbabwe: Harare | Malawi: Lilongwe | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zimbabwe: Harare | Mozambique: Maputo | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zimbabwe: Harare | South Africa: Randfontein | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zimbabwe: Harare | Tanzania: Dar es Salaam | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zimbabwe: Harare | Uganda: Kampala | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zimbabwe: Harare | Zambia: Lusaka | 20 | 10 | NA | 0.25 | 2.50 | NA |
| Zimbabwe: Harare | Other | 20 | 10 | NA | 0.25 | 2.50 | NA |

**Table A3.2: Assumptions on import parameters**

| **Importer** | $m_{ij}$ | $k_{ij}$ | $l_{ij}$ | $\beta_1$ | $\beta_2$ | $\beta_3$ |
|---|---|---|---|---|---|---|
| Kenya | 50 | -20 | NA | 0.80 | 8.00 | NA |
| Malawi | 20 | 30 | NA | 0.40 | 4.00 | NA |
| Mozambique | 20 | 50 | 140 | 0.06 | 0.55 | 2.75 |
| South Africa | 60 | -10 | 35 | 1.98 | 19.84 | 138.91 |
| Tanzania | 35 | 0 | NA | 0.65 | 3.25 | NA |
| Uganda | 100 | -50 | NA | 0.65 | 6.50 | NA |
| Zambia | 0 | 45 | NA | 0.09 | 0.45 | NA |
| Zimbabwe | 10 | 0 | NA | 0.15 | 3.00 | NA |