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Price transmission for agricultural commodities in Uganda: An empirical vector autoregressive analysis

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UGANDA STRATEGY SUPPORT PROGRAM (USSP) WORKING PAPERS

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Abstract

This paper investigates price transmission for agricultural commodities between world markets and the Ugandan market in an attempt to determine the impact of world market prices on the Ugandan market. Based on the realization that price formation is not a static concept, a dynamic vector autoregressive (VAR) model is presented. The prices of Robusta coffee and sorghum are examined, as both of these crops are important for the domestic economy of Uganda – Robusta as a cash crop, mainly traded internationally, and sorghum for consumption at household level. The analysis focuses on the spatial price relations, i.e. the price variations between geographically separated markets in Uganda and the world markets.

Our analysis indicates that food markets in Uganda, based on our study of sorghum price transmission, are not integrated into world markets, and that oil prices are a very determining factor for price transmission within the country. However, the case is a bit different for the cash crop, Robusta coffee. In the period in the 1990's with high coffee prices on the world market, prices in Uganda were strongly connected to world prices, and did not depend on the oil price. This indicates that if high demand appears in world markets, such effects could transmit to local markets. Thus, price transmission from world markets has only been evident in the case of booming prices of an exported commodity, but otherwise agricultural commodity markets are poorly linked. The empirical analysis thus indicates that rising food prices (of little-traded crops) on world markets will not have a direct effect on food prices in Uganda.

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1. Introduction

The aim of this paper is to investigate price transmission between world markets and the Ugandan markets in an attempt to determine the impact of world market prices for agricultural commodities on the Ugandan market. Based on the realization that price formation is not a static concept and that price transmission are equally, or perhaps more, interesting than market integration equilibria, a dynamic vector autoregressive (VAR) model is presented. [1]

The analysis seeks to provide insights into how rising food prices on world markets might affect the Ugandan markets. The topic of this paper is motivated by an issue which was widely debated in public in 2007 and 2008: the increases in food prices on world markets and the implications of the rising prices for the world's poor. In order to limit the scope of the paper and make the analysis as concrete as possible, the analysis is limited to one single country, namely Uganda.

This paper will analyze the prices of Robusta coffee and sorghum. Both of these crops are important for the domestic economy of Uganda; Robusta as a cash crop, mainly traded internationally, and sorghum for consumption at household level. This analysis focuses on the spatial price relations, i.e. the price variations between geographically separated markets in Uganda, and the world market. The spatial price transmission of sorghum and Robusta coffee, respectively, will be investigated in an empirically-based VAR model, to look for price transmission and market integration. The world market prices will thus be considered exogenously determined. Together with the oil price, which is crucial to a landlocked country as Uganda, the world market and domestic prices of the two goods will be analyzed.

Sorghum prices are available at regional level, through the FoodNet databases, and will be used to account for regional differences on the Ugandan markets. By utilizing this price spread between regions, it is possible to obtain more robust results. Oil prices are included in the investigation, as transportation costs are known to be of great importance for the Ugandan economy. Uganda is landlocked and has poor infrastructure, driving up transportation costs for trade in agricultural commodities. The aim of this paper is not, as such, to investigate the two sectors, but rather to gain insights into the price dynamics between the world and Ugandan markets. The motivation for choosing the particular commodities studied will be presented below.

The method that will be used is a non-structural approach using the data as the point of departure. Therefore we start by defining some general concepts of price transmission that will help us determine which variables are relevant for investigating the transmission process. However, no structural model is defined. The strength of this method is that the analysis will not be affected by a priori assumptions of structural relationships, allowing the data to give us evidence of the equilibrium forces of the transmission. The drawback of the non-structural co-integration analysis is obviously the lack of a theoretical framework within which to analyze the results. The investigation presented in this paper differs from most applications of the VAR model in a price transmission context by including transaction costs in the analysis; this will be further motivated by the theoretical models presented below.

[1] In conducting the research described in this report, we are very grateful for the help and support we have received from several people and bodies: Henrik Hansen and Henrik Zobbe for supervising our thesis; Danida (Travel Grant), ECON Pöyry, KVL's Jubilæumsfond, Novozymes, and Oticon Fonden for providing financial support for our field trip; Kirsten Halsnæs for all her guidance; Rilla Norslund for providing help and information; Todd Benson for all his files on data sorting, relevant literature and for providing FoodNet data; James Byekwaso, David Lule, Dr. Muwanga and Warwick Thomson for allowing us to interview them; and staff at ASPS II in Kampala, Jamie Morrison and the UNEP RISØ Centre.

2. Price transmission

2.1. Motivation for price transmission analysis

Seventy-five percent of the world's poorest live in rural areas (World Bank 2008a), and are thus highly dependent on agriculture. Despite this, agricultural sector development has not received the same amount of attention as other sectors. With the so-called Washington Consensus of the 1990s, agricultural subsidies were more or less banned, with the slogan "stabilize, privatize and liberalize" (Rodrik 2006). At current, only 4 percent of government expenditures in the least developed countries are aimed at the agricultural sector and only 4 percent of official development assistance flows were in 2008 directed towards this sector (World Bank 2008b).

Despite many of the opinions voiced during the "food crisis" in 2007-2008, rising food prices might provide a unique opportunity for agricultural development and poverty reduction, if the rising prices reach the poorest farmers. In Uganda for instance, several stakeholders described how many people might be reached through agricultural value chains. However, the potential positive effects of rising world market prices depends "upon markets receiving price signals, which, in turn, depends upon a number of markets' features, including their very existence" (Conforti 2004, 1). Investigating whether this is the case in Uganda is a main goal of our analysis. This will help us understand how world market conditions have in the past affected Uganda, and thus provide perspective on the likely impacts of rising global food prices. The topic of price transmission is important for policymakers, as it has a direct affect on aggregate economic welfare (Rapsomanikis et al. 2004, 51).

A main assumption behind the investigation in this paper is that complete market integration would enable the Ugandan economy to obtain gains from trade and exploiting comparative advantages in the production of agricultural products. Market integration is here meant as the ability of markets to receive price signals (transmission) and is thus crucial for market reforms to actually improve market performance. In turn, market structures are crucial for the degree and speed of price transmission. This paper focuses almost exclusively on spatial price transmission and will only refer to vertical price transmission (and value chains) where necessary.

2.2 Models of price transmission

Market integration is an equilibrium condition, and is thus not particularly interesting to study in itself, as the assumption of markets being in equilibrium seems unrealistic. Thus, in order to investigate price determination, the nature of pricing dynamics is the main feature (following, for instance, Fackler and Goodwin 2001). Time series of commodity prices are characterized by time dependence (serial correlation) and non-stationary behavior. These features are rarely dealt with in theoretical models. Additionally, theoretical models often lack apparent testable hypotheses. Therefore, an empirical approach to investigating the dynamics of price determination between markets is suggested.

We use a theoretical framework, namely the Law of One Price (LOP), in order to place our study and results in a logical framework. The LOP states that prices of homogenous goods will, in equilibrium, equal each other, apart from the cost of moving the goods from one place to another. This theory recognizes that price determination is endogenous, as described by an autoregressive process. The following simple empirical relationship represents the Law of One Price:

$$p^1_t = \alpha + \beta p^2_t + \varepsilon_t \qquad (1)$$

The variables p^1 and p^2 represent prices in two different markets. In the current context, the markets are defined to be geographically separated. The α term is a constant corresponding to the price differential between two markets, which is most likely reflects transportation costs. Thus markets can be perfectly integrated and still have different prices. The εt term is an error term. If prices are stationary (or trend-stationary), meaning they evolve around a constant, non-time-varying mean, the above regression equation can be used to test for the Law of One Price. $\beta = 1$ indicates that the LOP holds in the strong form (i.e. that the prices are actually the same), while $\beta \neq 0$ indicates that the LOP holds in the weak form (i.e. there exists a relationship between the prices). Thus, $\beta \neq 0$ indicates that markets are integrated to some degree and have a relation to one another. $\beta = 0$ means that there is no relationship between the prices.

If prices are non-stationary, we aim to find a linear combination of the series that will ensure stationarity; we thus rearrange equation (1) to the following equation:

$$\varepsilon_t = p^1_t - \alpha - \beta p^2_t \sim I(0) \tag{2}$$

In this framework, the Law of One Price can be thought of as an equilibrium condition, from which there might be divergence in the short-run. Even though prices may not behave as explained by the Law of One Price due to market distortions, prices do tend to have a co-movement between markets. However, the prices might be connected in very complex ways, and might behave differently in the short and in the long-run. We will investigate how shocks to one variable affect the whole system, and will discuss causality by determining pushing and pulling forces. It is crucial to specify an empirical relationship that is stable over time to ensure that our model is able to predict the shocks that have been observed. When determining integrated price variables, there are three possibilities of relationships between these variables. They can be co-integrated indicating market integration, be related indicating price transmission, or not be related at all.

Limitations to price transmission

The current analysis attempts to find price transmission between two markets – the Ugandan market and world markets – in an attempt to identify whether the Ugandan markets are integrated with world markets. A prerequisite for such transmission is that trade occurs between the markets and transportation costs do not dominate the prices of the goods, as described by α in equation (1).

A lack of trade between goods can be caused by high transportation costs, or by a lack of market efficiency, meaning that arbitrage conditions are not being sought.

The arbitrage condition – Differences in consumer preferences and production costs might cause price differentials between markets. If a price difference exceeds the cost of moving goods, it will be profitable for producers in one market (market 1, low price) to sell their good to the market with the higher price (market 2, high price). This increases supply in market 2, which leads to falling prices on this market. At the same time, for a given amount of total supply, this movement of goods will decrease supply on market 1, driving up the price on market 1. This process will continue until prices only differ by the transaction cost. The market condition driving this process is known as the arbitrage condition and can be described by the Law of One Price. However, the premise of this argument is that the price that can be achieved by the producer from market 1 on market 2 exceeds the price on market 1 plus the cost of transporting the good to market 2. If this is not the case, trade will not occur, with the result that prices will move independently. Traders will, if markets are efficient, seek arbitrage opportunities until prices have equalized (when there are no more arbitrage opportunities to be sought), which means that prices have reached equilibrium levels. This implies that prices might differ from this equilibrium level in the short-run.

Market efficiency – Arbitrage conditions are used to determine efficiency of markets in the following way: If there exists an arbitrage opportunity that is not being sought, a market can be considered inefficient. Alternatively, inefficiency can also describe the existence of obstacles to trade. Such distortions cause a loss of efficiency. However, they do not mean that an efficient equilibrium level of prices cannot occur, but simply that the "time getting there" might be longer. However, these distortions can become so severe that trade does not occur. Such a condition can only be described as the greatest level of market inefficiency as benefits from terms of trade are not realized, given, of course, that these are positive. This situation often characterizes rural markets for smallholders in developing countries. Fackler and Goodwin suggest the following definition of market efficiency: “efficiency is generally meant to imply that the allocation of resources is such that aggregate welfare cannot be further improved upon reallocation of resources" (2001, 980). Efficiency is interesting from a theoretical point of view, but not quite as applicable in empirical work. The concept of efficiency is often implicit in other theoretical implications and tested hypotheses on market performance.

Transaction costs – This term is used to cover transport costs from one market to the other, costs related to obtaining information about markets, search costs related to finding a suitable buyer or seller, and other costs due to such issues as credit market imperfections. The definition and consequences of transaction costs are highly disputed, and not sufficiently investigated in empirical work (de Janvry and Sadoulet 2006). A classical definition of transaction costs is “the expense of delivering the goods to different purchasers; each of whom must be supposed to pay in addition to the market price a special charge on account of delivery” (Marshall 1890, 325). Transaction costs can be both fixed and proportional, depending on the type of expenditure. Transaction costs might hinder arbitrage opportunities being sought (for instance due to price bands within which people don’t trade), and thus prohibit full price transmission (Sexton et al. 1991). However, the presence of these costs does not hinder market integration nor the transmission of price signals. Rather, a less beneficial equilibrium will simply be reached than in the case of no transaction costs, limiting the gains of trade for increasing overall welfare. The presence of transaction costs can lead to a price band within which prices are not linked; movement out of this price band can require large shocks to the prices (Abdulai 2007). In the presence of transaction costs it can be interesting to investigate the speed of price transmission, as transaction costs might not be constant over time. In conclusion, large transportation costs can make trade unprofitable. However, their existence does not mean a rejection of market integration.

Especially in a developing country, transaction costs are highly relevant, as infrastructure and storage facilities typically are poorly developed and maintained, which increases transaction costs and isolates markets (Abdulai 2007). In addition, Uganda is a landlocked country, which means that all transactions on the international market become more expensive, as goods either have to be transported by rail (which is poorly developed) or road transport through neighboring countries to reach ships for transportation, or by air, which is the most expensive means of transportation. The price of oil and the political relationship with and in neighboring countries are also crucial factors governing the transaction costs faced by Uganda.

2.3 Price transmission in the Ugandan context

Uganda’s agricultural sector

Approximately 80 percent of Uganda's population live in rural areas, and 69 percent are employed in agriculture. Agriculture accounts for 30.2 percent of GDP, and 83 percent of exports. Most of Uganda's agricultural sector consists of small-scale farming, and most production is done by households with small landholdings. Uganda has been commonly known as the pearl of Africa due to high soil fertility and two annual rain seasons. Yields have in general been declining since the 1990’s, and many authors, including Pender et al. (2001), note that soil depletion is a widespread problem. This, along with climate changes, particularly changing rains, and increasing amounts of pests and diseases, is cited by Ugandan farmers as the main reason for food insecurity and poverty (Uganda, MAAIF & MFPED 2000). Only approximately 10 percent of households use inorganic fertilizers. Pender at al. (2001) estimate that farmers receive crop yields that are only one-third of the potential from the land, and indicate that poverty may be a reason for this, as the poorest households cannot afford to leave the land fallow for a season or acquire fertilizer, even if they have the strongest incentives to do so, since their land is often their only source of income. The land tenure and land rights system in Uganda is quite complex with roots in the colonial era. Property rights are not properly established nor reinforced, with four categories of land tenure being recognized in the Constitution of Uganda from 1995 (Uganda, MAAIF & MFPED 2000; Uganda 1995). Traditionally there has not been a market for land, and land has had a low value as an asset. In recent years, due to population pressure and thus the prospect of rising prices of land, speculators from the capital, Kampala, have started investing in rural land, particularly in the area surrounding Kampala. Such investments add to the pressure on land as a resource, as the land bought by speculators is often not cultivated (Muwanga 2008).

Uganda is a country based on agriculture, and the agricultural sector has been developing and growing ever since the 1960's, apart from in the 70's, where the whole country was paralyzed during the Amin regime. The Plan for the Modernisation of Agriculture (PMA) from 2000, points to the success of economic recovery programmes in the 1980's in bringing about macroeconomic stability and positive growth rates (more than 5 percent per annum) in the 1990's and 2000's. The agricultural policy in the 1990's focused on the following areas (Uganda, MAAIF & MFPED 2000):

- Rehabilitation of infrastructure for traditional exports and development of alternative exports.
- Removal of physical, technical and institutional constraints for agricultural development.
- Agricultural pricing, trade, and marketing liberalization.
- Strengthening agricultural research and extension.

Agricultural marketing has been liberalized, export taxes and other market distortions have been removed, and regulatory and promotional agencies have been set up for key export crops, along with quality control and market information dissemination. The role of the government is to ensure that smallholder farmers prosper by delivering public goods and dismantling barriers to production, processing and trade, but without direct involvement. In 2000, the government developed the Plan for the Modernisation of Agriculture (PMA), aiming to "eradicat[e] poverty by transforming subsistence agriculture and commercial agriculture (Uganda, MAAIF & MFPED 2000, v)." The overall aim is to eradicate poverty by augmenting the poorest farmers' capital assets (physical, financial, human and social assets). The main objective is the transformation of subsistence farming into an industrial, commercialized, modern and efficient agricultural sector through cross-sectoral technological development within two decades, i.e. by 2020.

Infrastructure

Infrastructure is of particular importance to the agricultural sector as it is crucial component of transaction costs in agricultural markets. There is considerable room for improving the quality of roads in Uganda. This makes transport between farms and markets very slow and cumbersome, inducing high costs of transport, and meaning that in some areas trade barely exists. This limits smallholders' ability to earn income and limits their access to inputs for production. Means of transport are mainly provided by middlemen, who mark up the price between markets and farmers. Approximately 50 percent of smallholders own some means of transportation[2]; most of it being bicycles or motorbikes, which are the most effective means of transportation due to the condition of the roads. However, with these means of transport, only small amounts of goods can be transported at a time. Infrastructure is also other things than roads and vehicles. Market information systems have developed during later years, through the use of radios, mobile phones and text messages in particular. An

[2] Own calculations based on UNHS 05/06.

estimated 67 percent of agricultural households own either a TV, radio, mobile phone or similar electronic equipment which greatly improves the household's information about prices, market opportunities and crops.[3]

Prices in Uganda

Agricultural prices in Uganda develop within a complex system, and can be analyzed in several different ways, potentially yielding different results. Spatial price transmission between different local equally-sized markets in Uganda, generally, is not that variable, but differs due to transportation costs (Byekwaso 2008).[4] However, prices differ greatly along the supply chain, where the price of common agricultural goods can double from farm to city. Additionally, prices at local markets (no matter the size) can differ due to local shocks or due to availability, i.e. the local harvest and how often traders operate in a local market. Due to the complexity of the value chain, smallholders, who are at the bottom of the chain for agricultural goods, might not experience rising prices following increased demand.

Prices of imported goods are often lower than the prices of the locally produced goods due to dumping of heavily subsidized production from other countries. This is a situation which may have a great impact on the Ugandan farmers and on the economy in general. Dumping of agricultural goods, particularly wheat and rice, from international markets will limit the possibility of market integration. When international prices rise, dumping ceases. If there is no excess production in Uganda at the same time, this might drive up prices due to a smaller quantity of goods available. This effect might only be regional within Uganda, due to the difficulty of market access and fragmentation of markets.[5] Additionally, it makes local farmers more competitive on their own markets. Rising prices on international markets might thus be seen as positive by the Ugandan farmers. Another effect of the rising food prices is an incentive for local producers to grow crops for import substitution, as imports become more expensive (Thomson 2008).[6]

The presence of humanitarian NGOs, especially World Food Programme (WFP) food distributions might distort market prices.[7] These NGOs import food to be distributed to people, especially in IDP camps[8], which blurs the picture of price transmission and limits the possibilities of finding price transmission. WFP tends to import food from, for instance, the USA, where prices traditionally are low. When international prices rise above the local prices, they start buying locally, contributing to larger markets for local producers, and greatly affecting price settings. This is thus an indirect affect on local food prices, which is thought to be positive for producers.

A bad harvest or political turmoil in neighboring countries influences the demand for goods from Uganda. Ugandan markets can also be influenced in other ways. For instance, the post-election violence in Kenya in January 2008 shut down transport and trade to Uganda, and thus fuel prices rose (due to the constrained possibilities for imports). There is anecdotal evidence that climate change has affected weather patterns and, consequently, affected agricultural production in neighboring countries negatively, while Uganda has not been affected in the same way. Thus Uganda has an advantage over its neighboring countries. Changes in imports and exports vary more on the basis of local production than on

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[3] Own calculations based on UNHS 05/06.

[4] Figure 5 gives an indication of this.

[5] There might also be an effect in the markets surrounding the demand from the World Food Programme for its national and regional operations, as the WFP will start to buy locally if international prices rise, increasing demand.

[6] Rice production in Uganda has increased significantly within the last few years. Increased rice consumption is linked to urbanisation and rising incomes. Ugandan farmers seek to meet this demand, but must produce it cheaply to be competitive with imported rice.

[7] There is a direct effect from the distribution of goods, but also an indirect effect: Thomson (2008) suggests that the presence of so many NGO's has undermined private sector development in the agriculture sector.

[8] There are a few "work for food vouchers" programmes; however, such programmes also can be market distorting.

international price changes (Thomson 2008). These changing conditions all affect price development in ways that are difficult to predict.

Perceptions in Uganda

In the beginning of 2008 the world was preoccupied with rising food prices and their effect on the poorest people of the world. Surprisingly, Uganda had in June 2008 not yet experienced the same levels of surging prices, and most Ugandan stakeholders interviewed for this analysis were not aware of the extent of the international food price crisis. However, the country did experience rising prices to some extent, and some of the mentioned factors are discussed below.

Several interviewees pointed to the fact that because of the dumping of food crops on the Ugandan markets under "normal" conditions (keeping prices artificially low), rising world agricultural prices seem to have positive indirect effects for farmers in Uganda. The rise in international agricultural prices in 2007-08 were associated with low supply and high demand on world markets, meaning that stocks had been emptied, and no surplus production was sent to countries like Uganda to be dumped (Byekwaso 2008). This could lower the downward pressure on local prices resulting from cheap imports, and local prices could rise.

Rising prices are thus generally seen as a positive thing. Smallholders are not aware of developments on international markets, but are aware of prices on local markets. (Moreover, some might not even trade on these, and thus not be affected by the prices at all.) Households that export are, however, more aware of world market prices, as deals are usually agreed in futures where the smallholder bears the risk (Lule 2008). Thus world prices are believed to transmit to local markets to a higher extent for exported crops than for non-exported crops (Byekwaso 2008). Several of the interviewees encountered in Kampala expressed a willingness towards accepting rising prices, if it is at the benefit of the agricultural population, as they thus consider it of benefit of the economy as a whole. The biggest hindrances to this are weak value chains, trade and infrastructural deficiencies, as well as "top level structural deficiencies" (Thomson 2008).

Description of the goods investigated

Two goods are investigated in this paper: sorghum, representing a traded food crop, and coffee, representing a cash crop. A graphical illustration of the prices of these goods on local and domestic markets can be found in Figures 1 to 4.

Sorghum is a grass crop used as grain or flour, and it represents a staple crop to many rural Ugandan households. According to FAO's production statistics database, sorghum constituted 4.2 percent of the area harvested in Uganda in 2006, and it is thus the seventh largest crop in terms of area harvested.[9] In 2005, sorghum constituted 5 percent of Uganda's agricultural imports (41,612 tons), 65 percent of which came from Italy and 29 percent from the United States (FAO TRADEStat). Regionally, Uganda only imports sorghum from Kenya, to whom it also exports. Otherwise, Uganda only imports sorghum from non-African countries. Sorghum is exported in smaller quantities to countries in the region.[10] Regional flows of staple food crops to and from Uganda are very important. This, together with the fact that prices are not necessarily equal between domestic markets in Uganda, and that a large part of the sorghum production might not be traded on the markets (as it is produced by subsistence farmers), it is important to include regional sorghum price variation within Uganda in the analysis, and to include both large trading markets and markets in areas where sorghum is produced. Sorghum production is thus, like most other staple foods which

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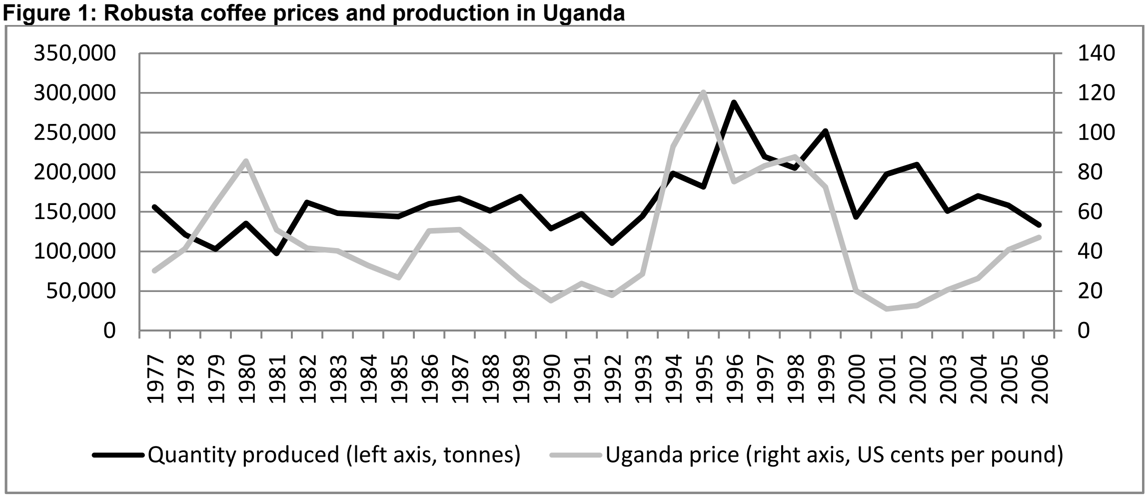
[9] The largest crops in terms of area harvested are matooke (banana) (22.8%), beans (11.6%), maize (11.2%), sweet potatoes (8%), millet (5.8%) and cassava (5.2%).

[10] In 2005 sorghum constituted 0.1% of total agricultural exports, composed of exports to Eritrea, Kenya and Sudan. (FAO TRADEStat)

the smallholder farmers are dependent upon, not necessarily expected to be a big part of the monetary economy.

Figure 1: Robusta coffee prices and production in Uganda



Source: FoodNet and ICO

Coffee is one of the traditional export crops in Uganda, and is the cash crop grown by the largest part of the population. It is highly integrated into Uganda's cash economy and into world markets, as practically all production is exported. Robusta coffee is investigated in this paper. Arabica coffee is also produced in Uganda but quantities are smaller, and a very high quality is needed for export. Robusta is thus a more common crop. Coffee is a perennial crop and requires good husbandry to produce well. However, the crop can be intercropped with other crops and can be left somewhat neglected for years without future production possibilities being affected. An estimated 20 to 30 percent of Uganda's foreign exchange earnings come from coffee. The industry employs over 3.5 million families up through the value chain and is entirely dependent on 500,000 smallholder farmers for production (UCDA web). Many smallholders have coffee plants on their land. However, whether they will cultivate the crop or not depends on prices. Due to the high value of coffee, and the fact that Uganda has sold coffee to world markets for many years, the supply systems are relatively well developed. Figure 1shows a close correlation between the coffee price on Ugandan markets and the quantity produced.

3. Empirical framework

This section considers the macro-economic approach to time series analysis. We present some of the main features of vector autoregressive (VAR) analysis and the basic definitions upon which the model is built. The model will be presented in subsequent sections. It draws heavily on Juselius (2006).[11]

The VAR model employed is a framework in which movements between time series can be defined by considering the auto regressive structure of the series. The variables p^1 and p^2, represent prices of the same good in two markets which are geographically separated. A co-integration relationship exists if there is a linear relationship between the prices that links the movements of the variables in a stable long-run equilibrium. This linear relationship is known as the co-integration vector, and can be used to test the Law of One Price, in either the strong or the weak form, depending on the exogeneity properties of the relationship.

[11] This method follows the trend in empirical studies, which have shifted from testing spatial arbitrage conditions to estimating spatial price transmission ratios (Fackler and Goodwin 2001).

Prices often contain a stochastic trend (for instance, inflation), making prices non-stationary over time. In a VAR model framework, one can utilize the non-stationarity of two variables to investigate common driving trends to the variables ("the system"). The idea is that the non-stationarity of the data might be caused by common shocks from other variables. This is the concept of price transmission as it is used to investigate market integration.

This section will describe the analytical framework that will later be applied to the empirical analysis. This paper focuses on two crucial aspects relevant for understanding the price formation mechanisms in Uganda – first, whether there exists co-integration between two time series variables (a long-run equilibrium condition) and, secondly, if shocks to one variable affects the other variables in the short-run. In this framework, divergence from the long-run is transitory, based on the spatial arbitrage condition (Rapsomanikis et al. 2004). If such a long-run relationship exists, the short-run parameters will describe the speed of convergence. The Law of One Price will have empirical support if a co-integrating relation of exactly this form is found to exist. These aspects will be investigated in the vector autoregressive (VAR) model framework, as described in Juselius 2006. The existence of a long-run equation will provide evidence that Ugandan prices are linked to world market prices, and the short-run parameters will describe in what ways the prices adjust to one another.

3.1 The model

The reduced form (unrestricted) VAR model (below) can be expressed as a vector of explanatory variables, $X_t' = (p_{1t}, p_{2t}\ldots)$ between which we are looking for a relationship. D_t contains an unrestricted constant and initial values of the explanatory variables, and other deterministic trends that might be needed, such as a linear trend.

(3) $$X_t = \Pi_1 X_{t-1} + \Pi_2 X_{t-2} + \varphi D_t + \varepsilon_t$$

$\Pi = \alpha\beta'$, where α represents the short-run parameters of the relationship, and β is a vector of long-run parameters. Significance of this parameter indicates a significant co-integrating relationship. The error term is assumed to be identically and independently normally distributed (*iid*), after checking for misspecifications and including relevant dummies.

The point of departure is equation (3). Stationarity will be inspected graphically, while the number of co-integrating relations and unit-roots are determined using several tests, the main test being the Trace Test procedure suggested by Johansen, supplemented by several others. One main strength of the applied analysis is that the determination of stationarity is not a yes-no answer, but rather an investigation into the properties of the Π-matrix. This is done by imposing reduced rank restrictions, and thus discussing the number of stationary components in the data explicitly. Secondly, lag-length determination is important for the analysis. This will be investigated through several information criteria, including the Schwartz (SC) and the Hannan-Quinn (H-Q) likelihood criteria, as well as the LR-lag reduction test. The lag-length should be determined through an iterative process, as the tests are quite sensitive to misspecifications of the model. Following Juselius (2006) a lag-length of one is rarely enough, while a lag-length of two often suffices to capture the dynamics.

3.2 The error correction model

If co-integration exists between two series that are integrated of the same order, the VAR model can be reparameterized as an error correction model (ECM), based on the Granger Representation Theorem. The ECM representation allows us to identify shocks to the relations of the system, where the short-run parameters (α) can be interpreted as a measure of the speed of transmission, while the long-run parameters (β) can be interpreted as the degree of price transmission between the variables. The error correction model builds on the unrestricted VAR in equation (3). The formulation deals with the time-lag that it takes for a time series to adjust back to the equilibrium relations.

4. Empirical analysis

This section will present the empirical analysis performed to investigate how changes in world market prices affect prices for sorghum and Robusta coffee in Uganda. Due to the nature of the empirical analysis, the investigation is performed in several steps, some of which will be presented more thoroughly than others. The remaining part of the paper will present an empirical investigation, and will sum up by relating the results to the research topic of this paper. The two analyses are presented alongside each other, to avoid repetition concerning the methods used. The data and hypotheses are described first. The model is then specified, followed by the actual analysis.

4.1 Data

For the empirical analysis, several sources were used. Table 1 presents the variables used in analyzing both the sorghum and coffee prices, along with the relevant sources.

Table 1: List of variables

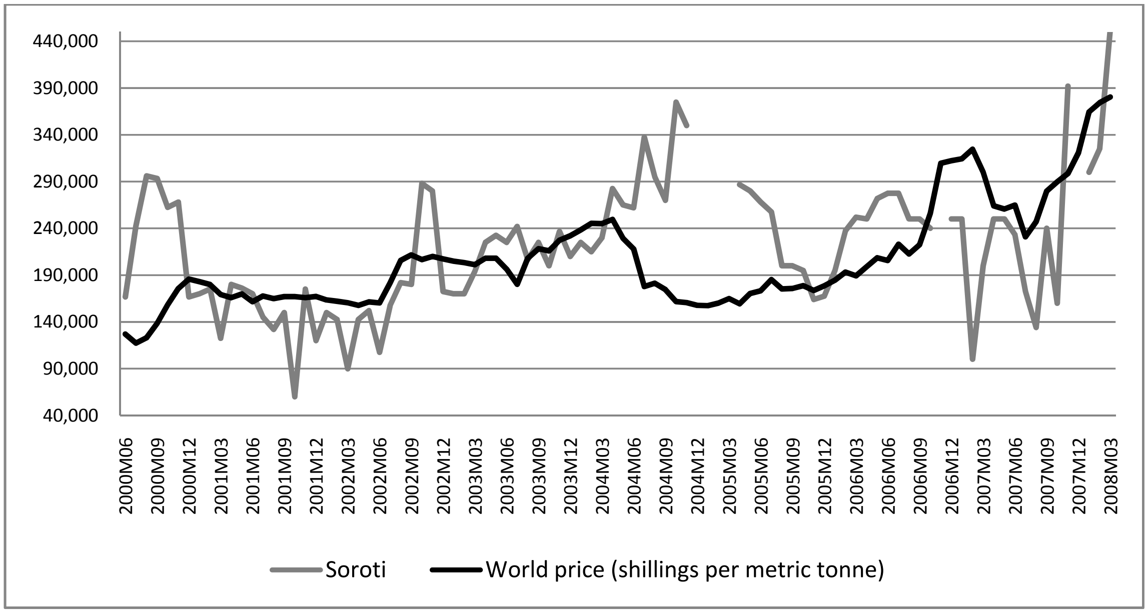
Variable	Description	Source
World (sorghum)	Monthly prices of sorghum, as an average of prices at main stock exchanges, US$. Converted into Uganda Shillings using average exchange rates from the Uganda Revenue Authority.	World Bank Global Economic Monitor
Gulu Jinja Mbale Soroti	Wholesale weekly prices collected at the main local market, in the four mentioned districts. Aggregated to monthly prices. (Uganda shilling)	FoodNet, in Uganda run by IITA.
World (coffee)	Monthly prices of Robusta coffee, as an average of exchange prices of the main exchanges, US$.	International Coffee Organisation
Uganda	Monthly prices paid to Ugandan producers at farm gate, US$, for Robusta coffee.	International Coffee Organisation
Oil	Price of crude oil. The same data is used for both the sorghum and coffee analyses, in Uganda Shillings, and US$, respectively. Aggregated average daily prices are used (reported in US$).	Energy Information Administration

Sorghum data

The data used for prices of sorghum in Uganda are based on data from the FoodNet market information project. FoodNet was run by the International Institute of Tropical Agriculture (IITA) between 1999 and 2008, financed by various sources, including USAID and the Ugandan national extension services agency, the National Agricultural Advisory Services (NAADS). Prices were collected throughout the country, but not in all districts, meaning that not all districts are represented in the dataset. Both wholesale and retail prices are collected for a large number of agricultural goods. The prices are collected every week, and have been converted into monthly prices for this paper, to avoid too many local fluctuations[12]. Data is available for 23 markets throughout the country, but many of the time series are incomplete, some even have more missing observations than observed observations. Four markets are chosen for the analysis. The sample used in this analysis stretches from June 2000 through September 2006. The sample is cut off at the latter point due to the beginning of the previously discussed food price developments in 2007-08. The oil price is included in the analysis to control for high transportation costs, and denotes the price of crude oil per barrel, measured as an index of the largest exchanges. Oil prices are averaged daily oil prices from the Energy Information Administration. Figures 2 and 3 depict the sorghum prices in the districts included in this analysis, as well as the world price.

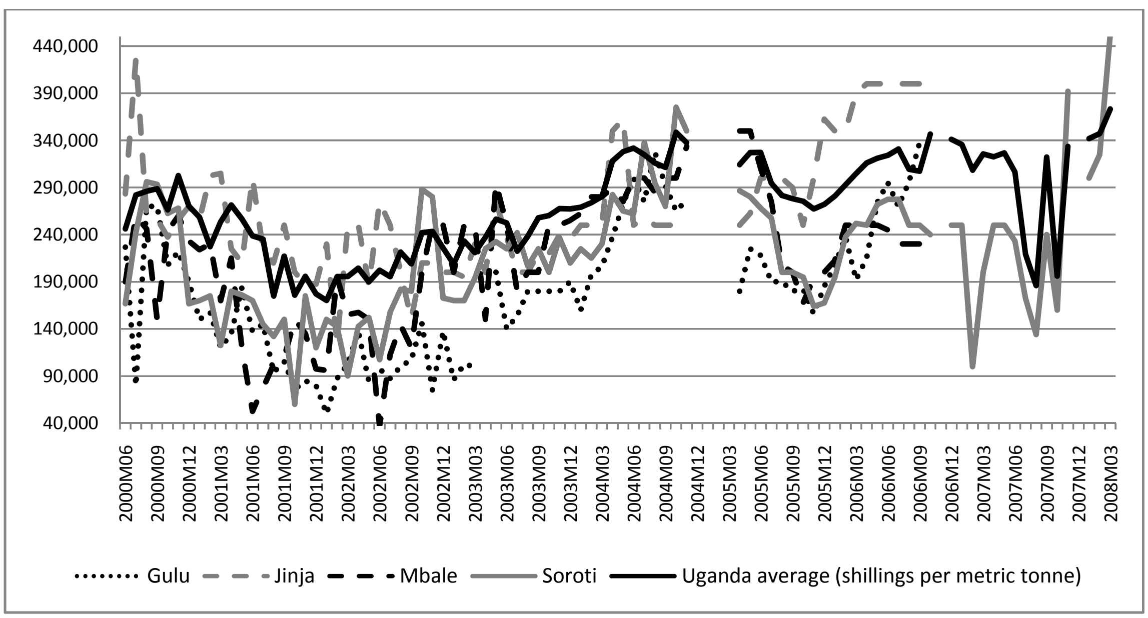
[12] Weekly prices can be quite volatile based on local factors, for instance high prices following heavy rains that might have made it impossible to travel to markets due to the condition of the roads. However, such price fluctuations are not relevant, and contain too much information when investigating the relationship with the international prices. Thus, weekly prices are aggregated even though these contain the most information.

Figure 2: Price of sorghum in Soroti, Uganda and on world markets



Note: Soroti market taken as representative of Uganda due to data availability.
Source: FoodNet, World Bank and Uganda Revenue Authority

Figure 3: Sorghum prices in Uganda



Source: FoodNet

Sufficient data for this analysis is available for 23 local markets. Of these, four markets are chosen for further investigation: Gulu, Jinja, Mbale and Soroti. These markets are main markets in their district, and will thus be representing these[13]. Jinja is located in the eastern part of the country, close to Kampala (80 km. / 2-3 hrs. drive). Gulu is located in the northern part of the country, and is the largest market in proximity to the IDP-refugee camps, and is

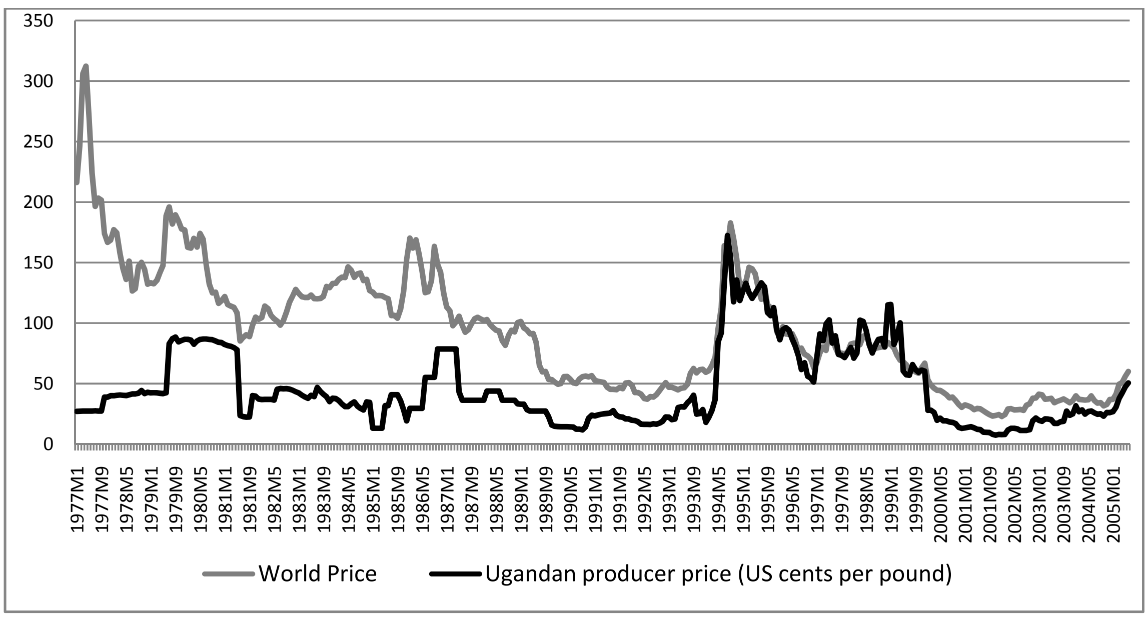
[13] Unfortunately, insufficient data were available for markets in the Western region.

thus a base for a large number of NGOs. The district is characterized as poor, insecure and having bad infrastructure. However, the market is developing quickly and sorghum has been promoted by NAADS since 2005, as it was already a main crop. Mbale is one of the largest markets in the country, and is situated in the east, very close to the Kenyan border. The district does not grow sorghum, but it pursues a lot of trade with Kenya, which is the reason why the market is included in the analysis. Soroti lies in the northern region and is one of the main sorghum growing areas in the country, even supplying the Nile Breweries with all the sorghum needed for its beer production. The stable demand from the Nile Breweries has ensured a high production. In Soroti, sorghum is promoted by NAADS, which has also provided improved seeds. These markets are chosen based on the above factors, but also based on cultural production patterns which indicate that sorghum is a main crop in the eastern and northern regions, even if the crop is only grown by 22 percent of the population.[14]

Coffee data

Coffee prices (both Ugandan producer prices and international prices) are from the International Coffee Organisation (ICO), and can be seen in Figure 4.

Figure 4: Correlation between Robusta coffee prices on the world and on the Ugandan market



Source: ICO

These prices are monthly, and are not converted into shillings, as both are reported in dollars by the ICO. Prices are available from January 1977 through April 2006. The period investigated will be January 1986 to April 2006, due to availability of oil price data. The world price (as an average of exchanges) of coffee and the price paid to Ugandan producers at the farm gate are compared. Both the minimum and the maximum of the Ugandan coffee prices are lower than the corresponding values for the world; a difference of about 10 US cents in recent years. As above, the oil price variable is included to allow for transportation costs.

[14] This also means that sorghum prices were not available for markets in the western region where sorghum is not as widespread.

4.2 Hypotheses

In the VAR framework we will investigate the relationship between the variables described above. Identification of common trends driving the system will shed light on the price transmission process, while the identification of a co-integrating relation between two non-stationary series will indicate that a market integrating relationship exists. Oil prices are included in the analysis as energy prices might be vital to determining the presence of co-integrating relations. We expect there to be two common driving trends to the systems: the world price and the oil price, and we expect the Ugandan variables to be adjusting. The questions that will be investigated explicitly are:

- Are any prices stationary by themselves? This would indicate lack of common driving trends and thus lack of market integration.
- Is the world price excludable from the structure in the long-run? This would imply a rejection of the Law of One Price.
- Is there a co-integrating relationship between a local price, the world price and oil? This would imply support for the Law of One Price, where transportation costs explain the differences between the prices in the spatially separated markets.
- Are oil and world prices driving forces of local prices in the long-run? (And if so, which one dominates?) This will be investigated in the moving average (MA) representation of the model and by inspection of the gamma matrices.

The test for market integration thus consists of two parts: 1) Determine the order of integration of the variables. Are the variables stationary? If no, proceed with the co-integration analysis to test for market integration. If the prices are stationary, traditional regression analysis and causality tests can be used to test for the law of one price. This indicates that there might be a market integration relation between the prices, but erodes the conclusion that the price transmission progress is of interest. The LOP is a static relation where differences between prices are explained by price differentials and markups, rather than common driving trends. 2) Search for co-integration between the non-stationary variables. If a stationary long-run relation is found, conclude that the markets are integrated, and continue to investigate the characteristics of this integration. If no co-integration relationship is found, conclude that the markets are not integrated. The oil price might be stationary; however this would mean that it cannot enter into a stationary co-integrating relationship with the two non-stationary variables.

Sorghum

Due to the small amounts of trade, and due to the local nature of shocks to the price, we cannot expect strong price signals between distant markets. Food distributions of sorghum in the northern region might blur the finding of price transmission, acting as a market distortion hindering the seeking of arbitrage in those areas. The identification of transmission might also depend on other variables than the ones included in this analysis, even if the Law of One Price does not dictate so.

Figure 3 shows that prices between local markets in Uganda cannot be considered homogenous, suggesting that the pricing pattern for sorghum is more complex than dictated by the Law of One Price. We can thus expect several driving forces behind the price development, including the world price, and signals from main domestic markets.[15] Additionally, we expect the oil price to be a driving force behind the domestic sorghum prices, as high transportation costs provide a price mark-up when transporting goods from one market to another.

Another co-integrating relationship might involve market integration between regional markets in Uganda, especially between the largest areas of production and the largest

[15] Also see Kuteesa 2005 and Benson et al. 2009, which is some of the limited research performed within this area.

trading centres, particularly the ones in close proximity to the Kenyan markets, where it is known that some of the produce goes. Large markets are more likely to be affected by world price trends than the production areas within the country, due to the value chain structure in Uganda, where prices can easily multiply from the farm to a market 100 km away. Finally, the Ugandan sorghum prices are expected to be influenced by several local shocks. It is impossible to guess how many there might be of these. There might be shocks that hit the economy as a whole, and there might be local shocks (for instance weather or disease) that influence demand and supply differently throughout the country. Additionally, there is a lot of substitution between staple crops in Uganda – if one crop has a bad season consumers simply shift to another crop (bounded by cultural barriers). This means that diseases or other shocks to production for other crops might also affect the demand for sorghum. Also, there may be shocks in form of demands from neighboring countries that drive up the prices. This could be caused by political instability (for instance the post-election violence in Kenya or the unstable situation in Sudan) or bad harvests. In any case, the most likely co-integrating relations would be one between one or several Ugandan variables and the international prices, and one between the Ugandan prices, where the oil price might again be included.

We expect to find pricing signals, in one way or the other, but it is difficult to hypothesize about the number of co-integrating relations between the Ugandan variables, and thus the rank. The Ugandan price variables are not purely adjusting, even though we expect world prices and oil prices to be driving trends to all domestic prices. The prices and harvests in the main producing district, Soroti, can be hypothesized to drive prices, while the largest trading centres (Soroti and Gulu) might adjust to this price. It is hard to predict anything about the price in Gulu. Kuteesa (2005) concludes that the sorghum price in Gulu adjusts for beans and maize markets, which can be due to the WFP influence. However, as Gulu is a main sorghum producing district, we expect price setting behavior in the Gulu sorghum market.

Coffee

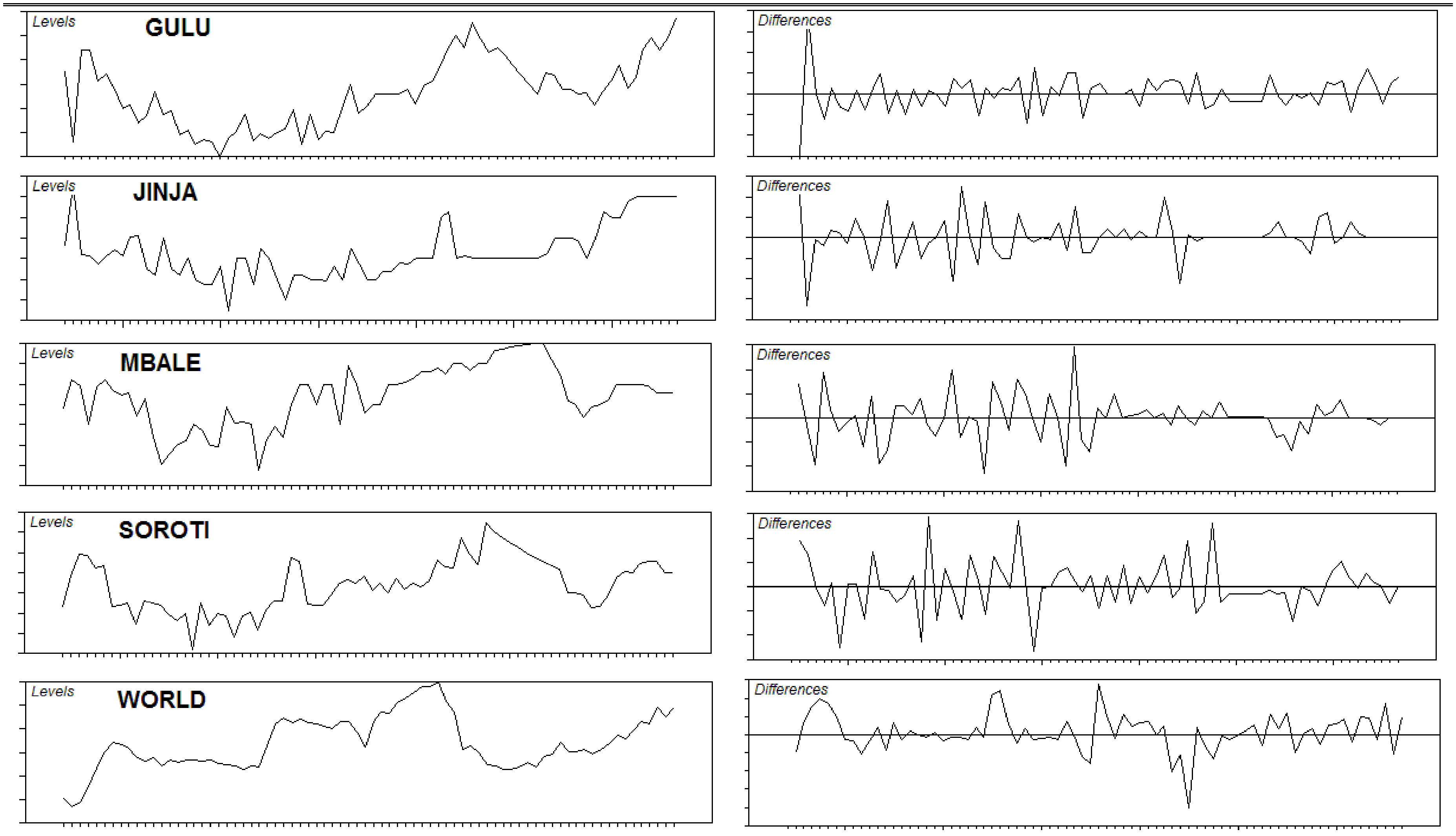
Our a priori hypothesis is one of market integration between the international coffee price and the Ugandan coffee price, and that the oil price might be a common driving trend to these variables, as transportation costs are believed to drive a wedge between the prices of spatially separated markets. Oil price is thus included as a proxy for transportation costs, something that is realistic in the case of Uganda, as the country is landlocked. Especially after the liberalization of the coffee sector in the early 1990's, transportation costs are hypothesized to be the most influential factor affecting the Ugandan market price after the international coffee price (i.e. rather than trade barriers and monopoly price settings etc.). In Uganda, producers sell their goods directly to exporters, ensuring connection to international prices. Rapsomanikis et al. (2004) find evidence of one co-integrating relation between the domestic and international coffee markets, and conclude that market integration is present based on the fact that Ugandan producers sell their goods directly to exporters, ensuring a connection to the international prices. They find symmetric and rapid adjustment (5 months, with a small error correction coefficient of -0.18), and conclude that domestic prices for coffee in Uganda are "Granger-caused" by world market prices, and that Uganda is a price taker.

We expect to find the coffee price to be non-stationary, markets to be integrated, and the world and oil prices to be common trends, with the Ugandan coffee price to be purely adjusting. This indicates a rank of two with two co-integrating relations.

4.3 Model specification

The aim of this section is to come up with well specified models for further analysis. To do this, we investigate the data series, search for economic reasoning and historical facts that can explain the developments of the series, and include deterministic components. No conclusions are drawn in this section, which is merely a stepping stone for further analysis.

Figure 5: Graphs of sorghum prices in Gulu, Jinja, Mbale, Soroti and the world market, in levels and first differences. June 2000 – Sept. 2006



Sorghum

Figure 5 shows the price series used, in levels and differences. Gulu, Jinja, Mbale, Soroti and the world prices display mean reverting behavior after taking first differences and are accepted as being *I(1),* i.e. stationary (see the right panel). In the Jinja and Mbale series there seems to have been a structural break in the middle of the sample, leaving two periods with constant variance. The oil price (shown in Figure 6 below), on the other hand, displays mean reverting behavior in the levels (allowing for a broken trend), and thus no differencing is necessary. This will be discussed more thoroughly when observing a longer time series in the coffee analysis.

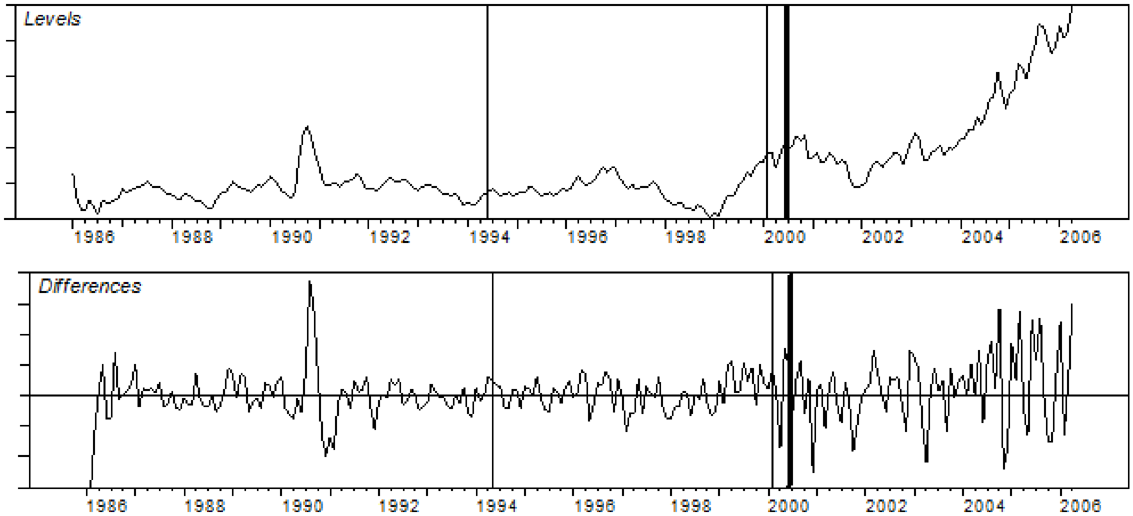
In the Soroti sample, there were several large outliers in the month of October. This can be explained by the fact that Soroti is a main sorghum producing district, and the main harvesting season for sorghum is October. For instance, the price dropped to half in 2001, following a good harvesting season. In October 2002 the price doubled while it rose by 30 percent after the harvest in 2004, indicating bad harvests both years.

The model is specified with an unrestricted trend, and with seasonal dummies, as agricultural goods are considered. Based on the smallest test size in the lag reduction test in Table 2, the lag-length is set to two. The H-Q information criterion indicates a lag-length of five, while the SC suggests a lag-length of one. However, based on autocorrelations (not provided) a lag-length of two seems sufficient. Misspecification tests and constant parameters are presented in Appendix A, and, based on the conclusion that the model is sufficiently well specified, we continue with the described model.

Table 2: Lag reduction tests

Lag reduction test	Test size	*p*-value
VAR(4) << VAR(5)	X^2 (36) = 154.181	[0.000]
VAR(3) << VAR(5)	X^2 (72) = 246.955	[0.000]
VAR(3) << VAR(4)	X^2 (36) = 92.774	[0.000]
VAR(2) << VAR(5)	X^2 (108) = 346.432	[0.000]
VAR(2) << VAR(4)	X^2 (72) = 192.251	[0.000]
VAR(2) << VAR(3)	X^2 (36) = 99.477	[0.000]
VAR(1) << VAR(5)	X^2 (144) = 433.783	[0.000]
VAR(1) << VAR(4)	X^2 (108) = 279.601	[0.000]
VAR(1) << VAR(3)	X^2 (72) = 186.828	[0.000]
VAR(1) << VAR(2)	X^2 (36) = 87.351	[0.000]

Figure 6: Graphs of the world oil price levels and first differences, Jan. 1986 – April 2006

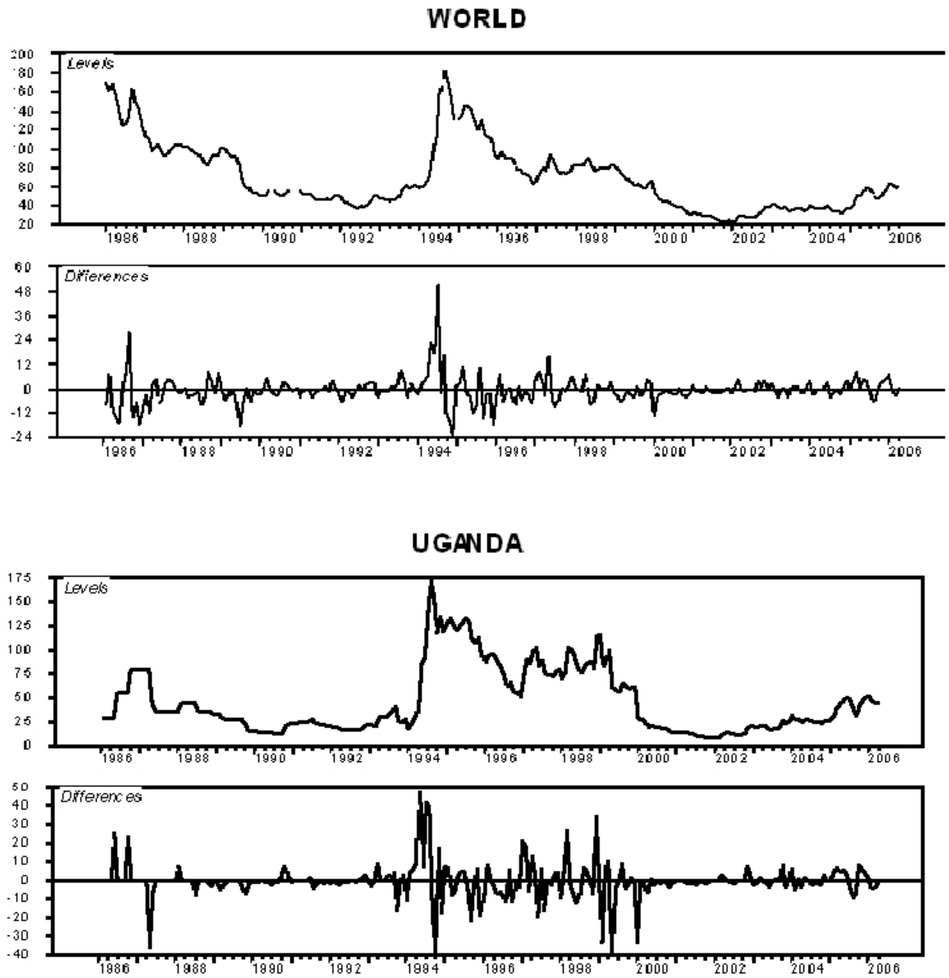


Note: The thickest line indicates the start of the sorghum sample; the two thin lines indicate the split of the coffee sample. Over the time period graphed, world oil prices fluctuated between US$ 10.63 and 69.85 per barrel.

Coffee

Coffee prices are used in levels, and seasonal dummies are included. All three series are mean reverting in first differences, but there is clear evidence of structural breaks, based on the variance of the series, as can be seen in the bottom panels of Figure 7. The oil price seems to enter a new regime in the beginning of 2000, while the coffee prices experience a bubble from 1994-2000. The oil price is potentially stationary in levels if the sample is split according to the suggested structural break. This might also be the case of the Ugandan coffee price, if the bubble is controlled for.

Figure 7: Prices of Robusta coffee on the world and the Ugandan market, in levels and first differences, January 1986 – April 2006



Note: For analytical purposes, the Robusta sample is split into two subsamples from May 1994 to January 2000 (the price bubble) and from February 2000 to April 2006. Over the time period graphed, world Robusta prices fluctuated between US$ 7.30 and 182.78 per metric ton.

When coffee prices rose dramatically in 1994 it led to a large increase in coffee production in Uganda. However, the price of coffee soon dropped. Thus, looking at the coffee prices over a longer time span from the 1980's up to today, the rise in prices seems like a bubble, rather than a regime change as it was once thought to be. The prices in 1994 were caused by a worldwide coffee shortage (mainly caused by frost in Brazil, the largest coffee producer in the world), and it was believed that Africa now had a real role to play on the world markets (ICO web). Interesting to note is that the large increase looks more like a regime shift in the Ugandan prices than in the world prices. For the world market, the rising prices lasted only three weeks, and fell back down within a few months.

Graphical inspection of the model parameters and likelihood functions support the historical developments described above, as can be seen from Figure 8. The coffee sample is thus divided into sub-samples, two of which are investigated further[16]: the regime from May 1994

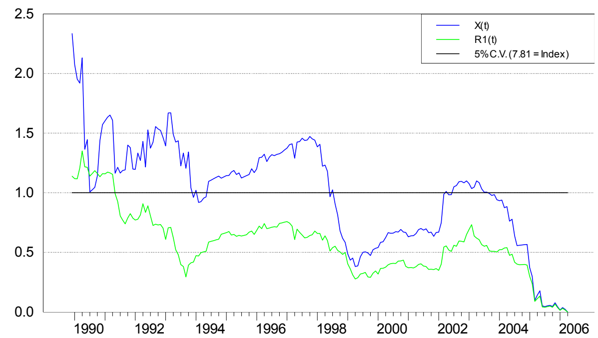
[16] Prior to 1994, the Ugandan economy had not yet been liberalized, and thus marketing boards are likely to have acted as price buffers towards world price transmission. To some extent, however, this might be the case for coffee, as the coffee marketing board is still in place. This might explain why prices dropped slower on Ugandan markets than on international markets.

to January 2000 (the price bubble) and from February 2000 to April 2006, the more stable period of low prices. The split ensures parameter constancy and provides for two models that are much better specified than the full sample.

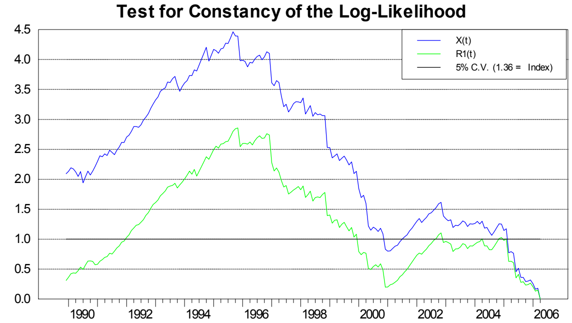
Figure 8: Constancy of the parameters of the Robusta coffee price. Test of Beta(t) = 'Known Beta' and test of constancy of the log likelihood function

Forwards recursive tests:

Test of Beta(t) = 'Known Beta'

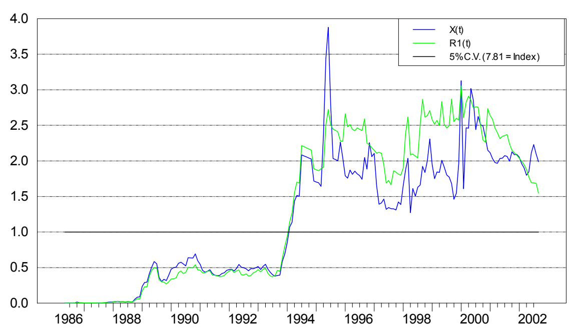


Test for Constancy of the Log-Likelihood

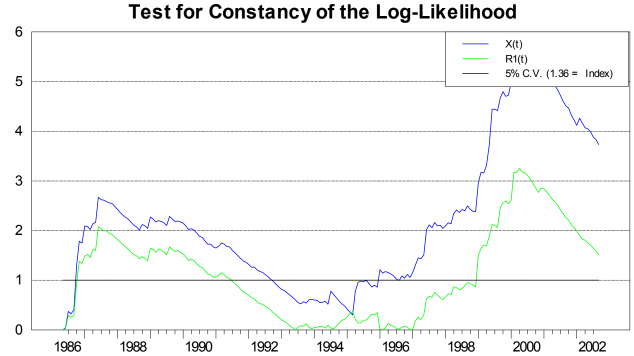


Backwards recursive tests:

Test of Beta(t) = 'Known Beta'



Test for Constancy of the Log-Likelihood



Note: The upper lines indicate the variables of the estimated equation; the lower, the reduced form.

Table 3: Lag reduction tests for both coffee samples

Lag reduction test	First sample		Second sample	
	Test size	*p*-value	Test size	*p*-value
VAR(4) << VAR(5)	X^2 (9) = 16.369	[0.060]	X^2 (9) = 21.594	[0.010]
VAR(3) << VAR(5)	X^2 (19) = 31.750	[0.024]	X^2 (18) = 36.815	[0.006]
VAR(3) << VAR(4)	X^2 (9) = 15.381	[0.081]	X^2 (9) = 15.221	[0.085]
VAR(2) << VAR(5)	X^2 (27) = 56.611	[0.001]	X^2 (27) = 43.174	[0.025]
VAR(2) << VAR(4)	X^2 (18) = 40.242	[0.002]	X^2 (18) = 21.580	[0.251]
VAR(2) << VAR(3)	X^2 (9) = 24.861	[0.003]	X^2 (9) = 6.359	[0.703]
VAR(1) << VAR(5)	X^2 (36) = 79.903	[0.000]	X^2 (36) = 68.141	[0.001]
VAR(1) << VAR(4)	X^2 (27) = 63.534	[0.000]	X^2 (27) = 46.547	[0.011]
VAR(1) << VAR(3)	X^2 (18) = 48.153	[0.000]	X^2 (18) = 31.326	[0.026]
VAR(1) << VAR(2)	X^2 (9) = 23.292	[0.006]	X^2 (9) = 24.967	[0.003]

In the second sub-sample, a dummy is included for April 2006, the last observation. The lag-length for the first sample is set to four, while the second sample is set to three, based on the lag reduction test in Table 3. For both samples, both the H-Q and SC information criteria suggest a lag-length of one, but due to improvements in autocorrelation and other misspecification tests when increasing the lag-length, long lag-lengths are adopted.

Comparing estimates of the two periods might provide insights into the different price structures due to the level of the prices.

4.4 Rank determination

Reducing the rank of the *Π*-matrix splits the sample into *r* (stationary) co-integrating relations, and ($p – r$) common stochastic trends that drive the system. Rank determination can thus answer the question "are there any common driving trends?" that would indicate price transmission. For both commodities we expect two driving trends: the world price and the oil price, indicating a rank of four for the sorghum analysis, and a rank of one for the coffee price. The main determinant of the rank is the trace test, including both direct standard errors, the Bartlett corrected sizes for small sample, and simulated critical values, for the relevant samples. The tables presented below should be read top down, with the null hypothesis of the rank indicated in the second column. The trace tests for sorghum and coffee prices are presented in Tables 4 and 5, respectively, and are discussed below. The α and companion matrices are presented in Appendices B and C. The measures are the graphs of the recursive trace test, the modulus of the roots of the companion matrix[17], the t-values of the unrestricted *α*-matrix and the graphs of the co-integrating relations.

A conclusion of full rank, which is the number of variables in the system, will indicate that there are no common trends driving the variables, and thus there are no price transmission, indicating that each of the price variables are driven by a unit-root process. A reduced rank conclusion indicates the presence of common driving trends, and the presence of long-run relations between the variables.

Table 4: Trace test of sorghum

p-r	r	Eigen-value	Trace	*p*-value	Simulated *p*-value	Trace*	*p*-value*	Simulated p-value	Frac95
6	0	0.688	206.858	0.000	0.000	186.591	0.000	0.000	117.451
5	1	0.514	120.561	0.000	0.000	109.829	0.000	0.000	88.554
4	2	0.386	67.217	0.024	0.020	62.153	0.067	0.059	63.659
3	3	0.175	31.183	0.440	0.431	25.528	0.763	0.756	42.770
2	4	0.125	16.973	0.425	0.428	9.322	0.943	0.942	25.731
1	5	0.092	7.120	0.342	0.349	4.893	0.618	0.621	12.448

(*) indicates Bartlett corrected sizes

The trace test of the sorghum sample is presented in Table 4 and strongly rejects a rank of zero or one. However, it is not clear whether a rank of two or three is correct. The other tests performed all strongly reject full rank, indicating that there is co-integration and thus at least one driving trend. The graphs of the recursive trace test display at least one statistic that does not grow linearly, indicating a rank of no more than five. The modulus of the characteristic roots of the companion matrix indicates a rank of three when considering a drop from 0.840 to 0.557 as large. One or two of the co-integrating relations seem stationary; the rest are error correcting, but display long persistence. A rank of three is settled upon, indicating three common trends and three co-integrating relations.[18]

The trace test of the two coffee samples can be seen in Table 5. For the first sample the trace test indicates a rank of zero (meaning no co-integration) or a rank of one. The recursive test rejects a rank of three (full rank), i.e. rejects no common driving trends. The remaining tests show very different results; from the alpha-matrix suggesting a rank of one to the modulus of the roots of the companion matrices indicating a rank of three. All we can

[17] The companion matrix is a representation of the VAR that enables us to calculate the eigenvalues of the system, by solving a second-order polynomial of the form: $| I - \Pi_1\rho^{-1} - \Pi_2\rho^{-2} | = 0$ where ρ is the roots and Π the matrices introduced in equation (3), and *I* the identity matrix (here presented with a lag-length of two, following Juselius 2006). The characteristic roots are given by the inverse of the eigenvalues.

[18] The results are later tested for the robustness of this assumption.

conclude is that a rank of one cannot be rejected, which falls in line with the theoretical discussion where we suspected world price and oil price to be driving trends of the Ugandan coffee price. For the second sample, the trace test in Table 5 strongly rejects co-integration, while the remaining tests are quite vague. All in all, a rank of one is imposed on the first structure, while co-integration is rejected in the second sample.

Table 5: Trace tests for both samples of the Robusta coffee price

p-r	R	Eigen-value	Trace	*p*-value	Simulated *p*-value	Trace*	*p*-value*	Simulated *p*-value	Frac95
First coffee sample									
6	0	0.324	36.918	0.031		31.821	0.110		35.070
5	1	0.134	11.497	0.503		10.084	0.637		20.164
4	2	0.032	2.130	0.750		1.866	0.799		9.142
Second coffee sample									
6	0	0.245	30.715	0.141	0.123	28.296	0.231	0.206	35.070
5	1	0.087	10.437	0.603	0.589	9.706	0.673	0.661	20.164
4	2	0.052	3.850	0.447	0.427	3.446	0.512	0.492	9.142

Note: The *p*-values are not simulated for the first sample, as no deterministic components are included. (*) indicates Bartlett corrected sizes.

4.5 Conclusions based on the chosen rank

In order to analyse the consequences of the chosen ranks from above, several automated tests are performed. These will be discussed in relation to the chosen ranks from above in order to provide a view of the implications of this choice and to discuss rank robustness (i.e., if the results are very dependent on the restrictions imposed on the model). Four automated tests are used to identify the role of the variables in the long and short-run matrices. These are presented in Tables 6 and 7. It should be noted that our finding that oil is not stationary is not a problem for our purposes. We are not explicitly interested in knowing the relationship between oil and the coffee prices, but are mainly using the variable to control for divergences between the two coffee prices.

Several of the results found are not directly intuitive if compared with the graphical inspections. This will be further elaborated in the subsequent analysis. However, it should be underlined that the results presented are very dependent on the choices made regarding rank determination. These choices are not clear-cut. Thus, it is important to follow an iterative process and to review all results for robustness. The VAR framework is highly responsive to the information in the data, meaning that seemingly irrelevant fluctuations can impact the possibility of finding solid empirical relationships. The framework thus has a high rejection rate of co-integrating relations.

Sorghum

A rank of three is investigated in the sorghum analysis, which leaves three co-integrating relations and three common driving trends to be identified.

Table 6: Automated tests for the sorghum analysis

rank	Gulu	Jinja	Mbale	Soroti	World	Oil	Trend
Test of long-run exclusion							
1	3.106	11.904	31.527	16.866	1.660	3.276	0.134
	[0.078]	*[0.001]*	*[0.000]*	*[0.000]*	*[0.198]*	*[0.070]*	*[0.714]*
2	15.970	27.692	40.164	33.811	4.151	11.646	3.948
	[0.000]	*[0.000]*	*[0.000]*	*[0.000]*	*[0.126]*	*[0.003]*	*[0.139]*
3	26.522	49.096	49.580	55.516	6.258	27.073	18.658
	[0.000]	*[0.000]*	*[0.000]*	*[0.000]*	*[0.100]*	*[0.000]*	*[0.000]*
Test of stationarity							
1	71.584	64.584	69.653	56.789	62.688	63.274	
	[0.000]	*[0.000]*	*[0.000]*	*[0.000]*	*[0.000]*	*[0.000]*	
2	38.736	35.727	36.858	31.555	30.741	31.302	
	[0.000]	*[0.000]*	*[0.000]*	*[0.000]*	*[0.000]*	*[0.000]*	
3	21.516	19.713	20.105	18.564	13.502	14.011	
	[0.000]	*[0.000]*	*[0.000]*	*[0.000]*	*[0.004]*	*[0.003]*	
Test of weak exogeneity							
1	0.394	6.640	15.865	8.477	0.036	0.502	
	[0.530]	*[0.010]*	*[0.000]*	*[0.004]*	*[0.849]*	*[0.471]*	
2	3.889	23.756	18.945	11.200	0.746	4.764	
	[0.143]	*[0.000]*	*[0.000]*	*[0.004]*	*[0.689]*	*[0.092]*	
3	9.684	26.672	31.743	27.715	3.633	4.764	
	[0.021]	*[0.000]*	*[0.000]*	*[0.000]*	*[0.304]*	*[0.188]*	
Test of pure adjustment							
1	63.002	30.440	18.262	30.864	68.950	66.778	
	[0.000]	*[0.000]*	*[0.003]*	*[0.000]*	*[0.000]*	*[0.000]*	
2	30.424	9.172	13.190	14.552	36.129	35.042	
	[0.000]	*[0.057]*	*[0.000]*	*[0.006]*	*[0.000]*	*[0.000]*	
3	19.351	9.091	4.522	5.677	18.980	25.838	
	[0.000]	*[0.028]*	*[0.210]*	*[0.128]*	*[0.000]*	*[0.000]*	

As Table 6 indicates, the world price is long-run excludable for all choices of rank, thus indicating that there is no market integration between the world markets and the Ugandan sorghum markets. Our a priori hypothesis of two driving trends, and thus a rank of four, is not supported by the test of stationarity of the variables. If we only allow for two driving trends, all variables except Soroti can be considered stationary and thus not affected by any of those two driving trends. However, if three driving trends are allowed for, none of the variables are stationary by themselves. World and oil prices seem to be weakly exogenous and thus pushing forces to the system, which corresponds to the hypothesis. By imposing a rank of three, the hypothesis of joint weak exogeneity (WE) of the variables is accepted with a *p*-value of 0.209, based on the test size X^2 (6) = 8.415. The test is rejected on the unrestricted structure, with a *p*-value of 0.006. Depending on rank choice, Gulu might also be weakly exogenous; the test of adjustment is again very sensitive to the rank choice. For a rank of three, Mbale and Soroti are purely adjusting, while this is only the case for Jinja if a rank of two is imposed. Imposing a rank of three, the joint hypothesis of pure adjustment of the two variables is accepted with a *p*-value of 0.200 based on the test size X^2 (6) = 8.562. The above results indicate that Mbale and Soroti are purely adjusting, world and oil prices are weakly exogenous and the world price might even be excludable. None of the variables are stationary by themselves, indicating price transmission. World and oil prices being WE indicates that these are driving trends. However, another driving trend will need to be identified.

Coffee

By imposing a rank of one on the second coffee sample, we indicate that there are two weakly exogenous variables, namely the world and the oil prices. We suggest that these two variables are the driving forces, while the Ugandan price is purely adjusting, as hypothesized. The automated tests are presented in Table 7. However, the world price switches from pushing to adjusting if the rank is increased to two. The joint hypothesis of WE of the two variables is accepted with a *p*-value of 0.117 from the test size X^2 (2) = 4.297 if a rank of one is imposed, but rejected on the unrestricted structure (with a *p*-value of 0.015). This will be further investigated in the moving average representation of the model. If rank is increased to two, the coffee prices seem stationary, while the oil price is excludable from the long-run relations. The conclusions are thus very sensitive. A rank of one corresponds to the theoretical scenario of market integration, while a rank of two would reject the hypothesis, since the coffee prices are stationary by themselves.

Table 7: Automated tests for the analysis of the two coffee samples

	First sample				Second sample			
rank	**World**	**Uganda**	**Oil**	**Constant**	**World**	**Uganda**	**Oil**	**Constant**
Test of long-run exclusion								
1	8.806 *[0.003]*	11.820 *[0.001]*	5.041 *[0.025]*	10.877 *[0.001]*	0.269 *[0.604]*	7.599 *[0.006]*	13.647 *[0.000]*	2.977 *[0.084]*
2	15.949 *[0.000]*	18.716 *[0.000]*	6.000 *[0.050]*	11.917 *[0.003]*	2.920 *[0.232]*	9.846 *[0.007]*	14.194 *[0.001]*	5.511 *[0.064]*
3					9.137 *[0.028]*	10.575 *[0.014]*	4.096 *[0.251]*	
Test of stationarity								
1	11.954 *[0.003]*	8.878 *[1.012]*	19.132 *[0.000]*		14.183 *[0.001]*	14.110 *[0.001]*	15.054 *[0.001]*	
2	0.005 *[0.946]*	0.164 *[0.686]*	6.383 *[0.012]*		2.72 *[0.099]*	2.702 *[0.100]*	2.707 *[0.100]*	
Test of weak exogeneity								
1	2.942 *[0.086]*	15.914 *[0.000]*	1.47 *[0.235]*		3.316 *[0.069]*	3.390 *[0.066]*	10.747 *[0.001]*	
2	10.176 *[0.006]*	23.148 *[0.000]*	1.446 *[0.485]*		5.637 *[0.060]*	3.510 *[0.173]*	12.620 *[0.002]*	
3					12.306 *[0.006]*	25.278 *[0.000]*	3.576 *[0.311]*	
Test of pure adjustment								
1	15.984 *[0.000]*	4.297 *[0.117]*	23.286 *[0.000]*		12.961 *[0.002]*	15.565 *[0.000]*	4.038 *[0.133]*	
2	0.065 *[0.799]*	1.019 *[0.313]*	7.236 *[0.007]*		0.322 *[0.570]*	2.154 *[0.143]*	1.110 *[0.292]*	

Note: The tests provided for full rank in the second sample are Bartlett-corrected, and are provided due to the rank determination tests. The test of stationarity cannot be calculated with a reduced rank restriction. The test of pure adjustment cannot be performed due to a lack of degrees of freedom.

In the second period for the coffee analysis, the world coffee price is excludable if a common trend is imposed, while the oil price is excludable if no common trends are imposed, indicating that this variable is not a driving force in the long-run. Depending on rank choice, the variables may all be stationary, which corresponds to the rank determination tests that indicate that the long-run matrices have full rank (r=3), and thus each relation to be stationary by itself. This is supported by the results in Table 7, where increasing the rank induces stationarity upon the variables. The results from the short-run relations are very difficult to interpret, and will be investigated further later.

The split of the coffee sample seems to indicate a changing regime, from high market integration in the period of booming coffee prices that followed the liberalization of the coffee sector in Uganda and many other countries. However, with the extreme drop of coffee prices around 2000, the market integration seems to have been broken down, with the price now moving autonomously.

4.6 Identifying the co-integrating relations

This section will seek to identify the long-run co-integrating relations (where applicable), and thus identify an over-identified long-run structure of the model. The testing is done by imposing restrictions on a single row in the long-run beta relations one at a time, leaving the other relations unrestricted, and thus estimating with non-identifying restrictions. The null of all the tests is stationarity of the suggested co-integration vector.

Sorghum

Setting the rank to three indicates that there are three long-run relations. Our prior hypothesis is that there exists a co-integrating relationship between the Ugandan prices and the international sorghum and oil prices of the form (1, -1, -1). However, we cannot be sure what relationship exists between each of the local variables. If the oil price is included, it is possible to find co-integrating relations between the world price and several local markets, as suggested by the Law of One Price (see equations $CI_{A.1}$ to $CI_{A.5}$ in Appendix D). However, the world price is actually excludable from the structure in the long-run as indicated in Table 6. Oil prices, rather than world prices, are the driving force for the price development in all markets. The hypotheses in equations $CI_{A.1}$ to $CI_{A.5}$ are, thus, merely economic hypotheses placed on the data, and are not supported by the empirical evidence. As will be shown in the next section, this means that a long-run structure allowing for the world price cannot be identified.

However, we do find accepted co-integrating relations between the local markets and the oil price. The tests can be found in the Appendix D, and the accepted co-integrating relations (labeled *CI*) based on the Law of One Price are presented below as $CI_{1.1}$ to $CI_{1.5}$.

$$CI_{1.1} : (Gulu - Oil) + Jinja + 3{*}Mbale - 5{*}Soroti \sim I(0)$$
$$CI_{1.2} : (Jinja - Oil) + Gulu + 4{*}Mbale - 7{*}Soroti \sim I(0)$$
$$CI_{1.3} : (Mbale - Oil) + Jinja + Soroti \sim I(0)$$
$$CI_{1.4} : (Soroti - Oil) - Gulu + Jinja \sim I(0)$$
$$CI_{1.5} : (Gulu + Jinja - Oil) + 3{*}Mbale - 6{*}Soroti \sim I(0)$$

In conclusion, the Law of One Price is rejected, since the world price is excludable. However, the world price might affect the structure in the short-run, and the long-run structure will therefore be presented to be able to place restrictions on the C-matrix later. As can be seen from Table 6, the result of the world price being exogenous is robust to choice of rank, indicating that no co-integration in the form of the Law of One Price can be found.

Coffee

For the first coffee sample, the rank is set to one, indicating a single co-integrating relationship. The hypothesis from the Law of One Price is: $(Uganda - (World + Oil)) \sim I(0)$. The structure is tested with a Bartlett corrected test value of X^2 (3) = 12.937, which is rejected with a test size of 0.005. However, one other accepted structure can be found; the co-integrating vector $Uganda + Oil \sim I(0)$, with an unrestricted constant and allowing for the world price, is accepted with a *p*-value of 0.706. This again indicates the importance of the oil price for Ugandan prices.[19] However, the main conclusion is a rejection of the Law of One Price and of market integration. Since the second sample for the coffee price has full rank, this indicates that the variables are stationary, dismissing the importance of the gradual price transmission processes and common driving trends between the markets.[20]

4.7 The long-run structure – error correction model

In order to identify the Π-matrix, over-identifying restrictions need to be imposed in a way that ensures error correction. These are discussed below and are presented in Appendix D.[21] In

[19] For a rank of two the hypothesis is accepted with a *p*-value of 0.103. However, for a rank of two both the world price and the Ugandan price are stationary by themselves, as can be seen in Table 7. This indicates that the coffee prices should be driving trends to the oil price; a relationship that can be discarded, for obvious reasons.

[20] However, if one co-integrating trend is imposed, the structure is accepted with a *p*-value of 0.473. However, the result holds the same problem as discussed above, which is that the variables are stationary by themselves. For a rank of one, the relationship is rejected.

[21] The restrictions are based on the hypotheses tested in the previous section.

the case of sorghum, price homogeneity between Jinja, Mbale and Soroti is imposed in the structure, as well as co-integration between Gulu, Jinja and the oil price, and between Jinja, Soroti and the oil price. It is striking that the oil price is strongly significant in all relations, and that this price is a strong determinant of sorghum prices in Uganda. Additionally, market integration between the domestic variables in Uganda seems present (perhaps with the exception of Gulu).

For coffee, no long-run structures can be identified. The first coffee sample needs three restrictions imposed for the structure to be over-identified, but no combinations of the variables render an accepted structure. We can thus conclude that no long-run market integration exists between these variables. For the second coffee sample, the joint hypothesis of each variable being stationary by itself is accepted with a *p*-value of 0.722, based on the test size X^2 (3) = 1.329. Since no support is found for the Law of One Price, the structures are not informative by themselves. The structures are further used to identify common driving trends of the model in the following section.

4.8 Identification of common trends – the moving average structure

In the VAR model, common trends can be investigated by reparameterizing the model into a moving average (MA) representation:

(4) $$x_t = C\sum_{s=1}^{t}\varepsilon_s + C\mu t + C^*(L)\varepsilon_t + \tilde{\mathbf{X}}_0$$

Subscript *s* stands for “shock”. Thus the above equation shows that the variables can be explained as accumulated stochastic trends, $C\sum_{s=1}^{t}\varepsilon_s$ and stationary stochastic components, $C^*(L)\varepsilon_t$. Additionally, a trend, $(C\varphi t)$, and the initial values, (X_0), are included. The representation allows us to identify if a variable (or the shocks to a variable) can be considered a driving force to other variables in the system, thus labeling this a driving trend. Additionally, purely adjusting forces can be identified. The short-run parameters of the system can be investigated, from the above *C*-matrix, which is composed as:

(5) $$C = \beta_\perp (\alpha'_\perp \Gamma \beta_\perp)^{-1} \alpha'_\perp$$

The common stochastic trends can be found based on (the orthogonalized) estimates of β and α in the *C*-matrix, given the short-run impact matrix, gamma (Γ). By interpreting the parameters of the MA representation, pushing and adjusting forces to the system can be identified. The concept differs from that of common trends, as common trends imply co-integration. Even if co-integration is not found, we will be able to study the underlying characteristics of the movements in the data. We can study the variables which are determined by developments in other variables included in the analysis (characterized as purely adjusting) or variables that are partly driven by the variables in the system. We can also study the variables that are determined by forces outside the system, but that affect the system (such as the oil price), and investigate if any of the variables included in the system are determined by exogenous factors and not relevant to the remaining variables in the system (for example, if the Danish birth rate was included in the system).

The aim of this section is to further investigate the dynamics of the systems in order to identify common driving trends. This is done by investigating the short-run structure of the model, and the conclusions derived will later be held together with the conclusions about the long-run structure from above. We already have indications of what variables are exogenous from the automated tests presented in Tables 6 and 7. These results are investigated further by looking at the long-run impact matrix (*C*-matrix) and the Gamma matrix of the short-run parameters (see equation (4)). By inspecting the rows in the *C*-matrix, we can identify if the cumulated shocks to a certain variable affects other variables in the system, while a row-wise inspection tells us by which shocks a certain variable is affected. The rank determination tells us how many variables we need to identify, and the Gamma matrix will tell us whether any variables are excludable from the short-run structure (see equation (5)).

Sorghum

For a rank of three, Table 6 indicates that world and oil prices are weakly exogenous. This suspicion is confirmed by investigation of both the unrestricted and restricted Gamma-matrices presented in Appendix E. (The restricted matrix is based on the long-run structure and can be found in the section above in which the long-run structure is discussed.). The world price does not affect any variables of the system, while the oil price weakly affects only the price in Mbale. The *C*-matrices help us identify the common driving trends to the systems. With a rank of three and with world price being excludable, we must identify two common trends. Shocks to the oil price affect the prices in Jinja, Mbale and Soroti (resembling the first imposed relation in the long-run structure). The *C*-matrix in Table 8 confirms the results suggested from Table 6, which is that prices in Mbale and Soroti are purely adjusting, in line with our hypothesis.[22] The prices in Gulu affect the prices in Jinja and in Soroti, possibly because there is a large demand from Gulu or because there are market distortions in the form of World Food Program's presence, or because of other factors. The indication of price transmission from Jinja on the oil price is ignored, as there no economic reasoning justifies this result. The oil price influences the prices in Jinja, Mbale and Soroti. It is interesting to observe that the oil price does not influence the price in Gulu, which indicates the market distortions mentioned earlier. It does, however, affect the prices at the large trading centres, indicating that transportation costs are in fact a large issue and have a large impact on prices. It can be concluded that the Jinja and Gulu prices, together with the oil price, drive the sorghum price system, while Mbale and Soroti are purely adjusting.

Table 8: Sorghum – the unrestricted *C*-matrix

	$\hat{\varepsilon}_{Gulu}$	$\hat{\varepsilon}_{Jinja}$	$\hat{\varepsilon}_{Mbale}$	$\hat{\varepsilon}_{Soroti}$	$\hat{\varepsilon}_{World}$	$\hat{\varepsilon}_{Oil}$
ΔGulu	1.118 *(3.486)*	0.278 *(1.832)*	-3.350 *(-1.374)*	-0.361 *(-1.196)*	-0.093 *(-0.193)*	-2.050 *(-1.742)*
ΔJinja	0.192 *(1.293)*	0.201 *(2.858)*	-0.072 *(-0.607)*	0.023 *(0.163)*	0.228 *(1.023)*	2.061 *(3.778)*
ΔMbale	0.964 *(3.215)*	0.130 *(0.920)*	-0.252 *(-1.061)*	-0.268 *(-0.949)*	0.538 *(1.198)*	-3.887 *(-3.533)*
ΔSoroti	0.73 *(3.369)*	0.142 *(1.383)*	-0.200 *(-1.164)*	-0.193 *(-0.948)*	0.366 *(1.127)*	-2.211 *(-2.780)*
ΔWorld	-0.149 *(-1.191)*	0.012 *(0.211)*	0.096 *(0.966)*	0.210 *(1.784)*	1.114 *(5.955)*	0.532 *(1.162)*
ΔOil	-0.006 *(-0.142)*	0.043 *(2.334)*	-0.001 *(-0.036)*	0.027 *(0.751)*	0.080 *(1.371)*	0.701 *(4.931)*

The result is robust to the rank specification if the rank is increased to four. However, the results change quite dramatically when the rank is reduced to two, as Mbale, Soroti, Gulu and Jinja are all pointed towards as driving forces (see Appendix F for the *C*-matrices with a rank of four and two). However, the main result of this analysis is robust to the rank specification – the world price is exogenous, and the oil price affects local markets. Additionally, we can conclude that there is significant adjustment of the prices in Gulu and Mbale after only one time period, which is rather rapid, but not extreme, since the time period considered is one month.

Coffee

Since no long-run relationships exist between the variables of the coffee models, unrestricted gamma matrices presented in Table 9 are inspected (rather than the restricted matrices). The oil price might be strongly exogenous, and it seems there is a transmission from the world prices to the Ugandan prices. More striking is the effect from the Ugandan prices to the

[22] The result is robust to the restrictions specification – the unrestricted matrix in Table 8 can be compared to the restricted matrix in Table 20 in Appendix E.

world prices, which does not make economic sense under the hypothesis of Uganda being a small price-taker on world markets. However, this relationship might be due to high correlations between these two variables. For the second coffee sample, the oil price seems to be strongly exogenous, and there are some short-run relations that do not make much sense. However, given that the series are probably stationary by themselves, each series is a driving force for itself and no further inference can be made.

Table 9: Coffee – unrestricted Gamma matrices

	First coffee sample			Second coffee sample		
Γ_1	ΔWorld	ΔUganda	ΔOil	ΔWorld	ΔUganda	ΔOil
ΔWorld	-0.211 *(-1.408)*	0.350 *(3.234)*	-1.227 *(-1.737)*	0.189 *(1.279)*	0.289 *(2.125)*	-0.069 *(-0.667)*
ΔUganda	-0.932 *(-3.819)*	0.546 *(3.096)*	-1.761 *(-1.529)*	0.310 *(1.699)*	0.170 *(1.011)*	-0.153 *(-1.193)*
ΔOil	0.030 *(1.113)*	-0.032 *(-1.619)*	0.111 *(0.860)*	0.388 *(2.585)*	-0.295 *(-2.134)*	-0.037 *(-0.346)*
Γ_2						
ΔWorld	0.006 *(0.060)*	0.239 *(2.654)*	0.549 *(0.870)*	-0.184 *(-1.228)*	0.142 *(1.057)*	0.032 *(0.320)*
ΔUganda	-0.233 *(-1.365)*	0.191 *(1.298)*	-2.432 *(-2.364)*	-0.063 *(-0.342)*	-0.011 *(-0.067)*	-0.050 *(-0.403)*
ΔOil	-0.003 *(-0.164)*	-0.039 *(-2.382)*	0.089 *(0.770)*	-0.139 *(-0.912)*	0.071 *(0.516)*	-0.137 *(-1.342)*
Γ_3						
ΔWorld	-0.239 *(-2.823)*	0.093 *(1.115)*	0.726 *(1.157)*			
ΔUganda	-0.345 *(-2.495)*	0.273 *(1.998)*	0.771 *(0.754)*			
ΔOil	-0.012 *(-0.772)*	0.005 *(0.353)*	0.116 *(1.012)*			

Table 9 indicates that significant short-run adjustment of the Ugandan price can be found after one and three time periods, which indicates that the price transmission is rather fast. There could thus be some degree of market integration between the world coffee price and the Ugandan coffee price in the first sample. However, Table 9 also indicates that this adjustment is not present in the second sample, and that market integration has thus worsened after the coffee boom. Prices were thus more instantly transmitted when the prices were high. From the *C*-matrix for the first coffee sample presented in Table 10, we can conclude that world and oil prices are driving trends, while the Uganda coffee price is adjusting, which corresponds to the hypothesis. However, the oil price does not seem to affect the Ugandan coffee price.

Table 10: First coffee sample – the unrestricted C-matrix

	World	Uganda	Oil
World	1.560 *(3.707)*	-0.366 *(-1.601)*	0.108 *(0.057)*
Uganda	1.212 *(3.690)*	-0.327 *(-1.835)*	-1.633 *(-1.105)*
Oil	-0.149 *(-1.774)*	0.071 *(1.562)*	1.436 *(3.797)*

4.9 The economic model scenario

For the sorghum sample, three common trends were identified. These do not completely contradict the hypotheses presented at the beginning of this section. The shock to the oil price was expected to affect all variables, while shocks to the world food price were expected to affect all food prices. Additionally, one or more shocks affecting the Ugandan domestic markets and thus prices were expected to affect the Ugandan price variables. Based on the results from Table 9, the moving average representation of sorghum price formation can be set up, as shown in equation (6).

$$\begin{bmatrix} Gulu_t \\ Jinja_t \\ Mbale_t \\ Soroti_t \\ World_t \\ Oil_t \end{bmatrix} = \begin{bmatrix} 0.9 & 0.4 & - \\ 0.3 & - & 1.7 \\ 0.8 & 0.3 & -5.1 \\ 0.6 & 0.3 & -2.9 \\ - & - & - \\ - & - & 0.8 \end{bmatrix} \begin{bmatrix} \sum_{i=1}^{t} \hat{\varepsilon}_{Gulu} \\ \sum_{i=1}^{t} \hat{\varepsilon}_{Jinja} \\ \sum_{i=1}^{t} \hat{\varepsilon}_{Oil} \end{bmatrix} + trend + stat.comp \tag{6}$$

This scenario shows that the shocks from Gulu, Jinja and the oil price affects the prices of the other Ugandan models, but do not affect the World price. The three common driving trends are thus found. However, they do not correspond to the hypothesis from above which is mainly caused by the exclusion of the world market price, as the remaining conclusions are as hypothesised. Domestic shocks affect domestic variables and shocks to the oil price affect these variables as well. $\hat{\varepsilon}_{Gulu}$ represents a shock to the domestic variables – possibly a consumption demand shock. When the prices of sorghum rise in Gulu, we expect them to rise throughout the country. The second shock identified in equation (6) is another domestic shock – a shock to the price in Jinja is expected to spread throughout the country, possibly due to export demands. Finally, a shock to the oil price, $\hat{\varepsilon}_{Oil}$ drives the system, and most of the domestic markets. The fact that there is no adjustment of the Gulu price might be caused by market distortions. The result that Jinja is affected differently than Mbale and Soroti is more puzzling. The oil price does not affect the world price; but has a quite large numerical effect on the remaining variables.

For the first coffee sample, the model presented in equation (7) is found. We hypothesized that the Ugandan price would be affected by two trends, namely accumulated shocks to the world coffee price and to the oil price. The two driving forces were identified. However, the oil price seems to be independent of the remaining system, with shocks to the oil price only affecting the oil price in itself. This indicates a strong connection and high correlation between the coffee prices on the different markets being driven by the world price. For the second coffee sample, no economic scenario is identified as there is no co-integration between the variables.

$$\begin{bmatrix} World_t \\ Uganda_t \\ Oil_t \end{bmatrix} = \begin{bmatrix} 1.6 & - \\ 1.2 & - \\ - & 1.4 \end{bmatrix} \begin{bmatrix} \sum_{i=1}^{t} \hat{\varepsilon}_{World} \\ \sum_{i=1}^{t} \hat{\varepsilon}_{Oil} \end{bmatrix} + t + \ldots \tag{7}$$

5. Conclusions

From the analysis of the sorghum data, no evidence is found that Ugandan prices are linked to world market prices, rejecting market integration and the Law of One Price. The world price can be excluded from the system, indicating that it has no explanatory power towards any of the other variables. This result is probably due to the low amount of trade of Ugandan sorghum on the world markets and due to the lack of integration between the variables. The oil price is rather the determining factor of Ugandan sorghum prices. This makes sense both in a Ugandan and an international perspective, due to transportation costs. There does, however, seem to be interlinkages between the sorghum prices within Uganda.

For the coffee prices, there is evidence that the price transmission mechanism from the world market broke down after the coffee price boom in the 1990's. In the second coffee sample there are no signs of price transmission between the variables. The oil price variable has been named a driving force for the sorghum sample, but was not as important for the first coffee sample during times of strong price linkages. Diversification away from coffee as a traditional export crop might cause some of these effects. However, the diversification might also be caused by the lack of price transmission.

The analysis in this paper indicates that food markets in Uganda are not integrated as part of the world markets, and that oil prices are a determining factor for price transmission within the country. However, the case is a bit different for the cash crop, coffee. In the period in the 1990's with high prices due to low supply on the world markets, prices in Uganda were strongly connected to world prices and did not depend on the oil price. This indicates that if a high demanding market appears on the world markets, such effects could transmit to local markets. Thus, *price transmission from world markets has only been evident in the case of booming prices of an exported commodity, but otherwise markets are poorly linked. The empirical analysis thus indicates that rising food prices (of little-traded crops) on world markets will not have a direct effect on food prices in Uganda.*

6. Limitations to the analysis

As can be seen by graphically interpreting Figure 4, the conclusion of no long-run relationship between the global and Uganda Robusta coffee prices might not seem realistic. This can be a result of the type of model used, since the approach is empirical, based on the fluctuations observed in the data. The lack of synchronizing the data with a well-elaborated framework is often found to produce such results. However, the empirical approach is also a main strength of the model.

The strength of the VAR model is the possibility of investigating in more detail the causal inference, which cannot be done practically in, for instance, a univariate time series model, and in capturing the endogeneity of the variables. This is done by "letting the data speak", by using an iterative process and in not constraining the relationships by economic hypothesis, other than the simple, hypothetical constraints as expressed in the economic model and by the moving average structure. Other than this, the relationships described are purely empirical rather than economical. This explanation, with a weak (in the positive sense) imposed structure is supported by Sims (1987). Others have seen this as a lack of robustness of the model, leading to strong criticisms of the model. However, it should be noted that the investigation of the causal inference is not to be confused with the Granger causality; the results are very dependent on the specification of the model. For these reasons, the models have been criticized for use in policy analysis, as only conclusions in very weak terms are possible. However, with a lack of a trustworthy framework within which to more strictly analyze the data, the presented approach is deemed relevant.

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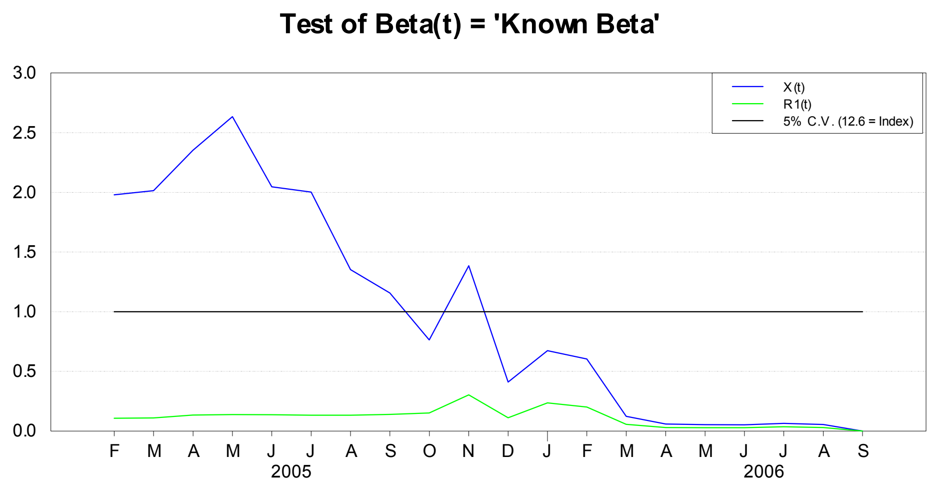
Appendices

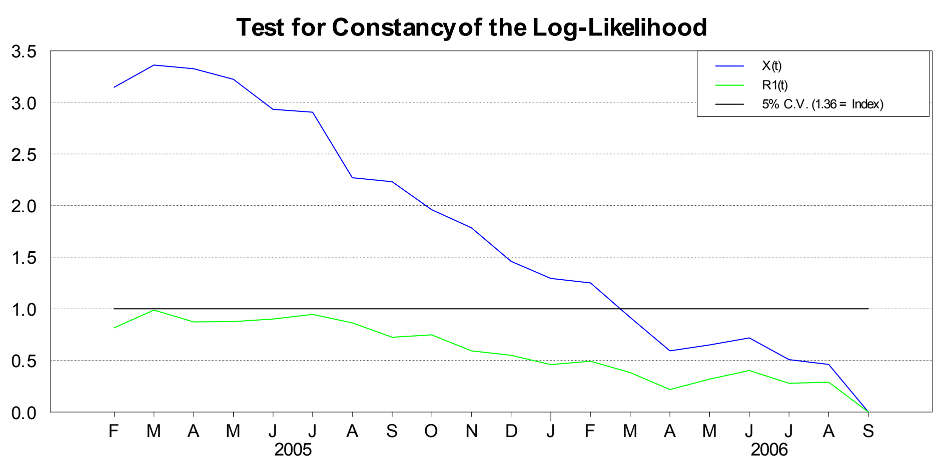
Appendix A – Misspecification tests for the sorghum sample

Table 11: Misspecification tests for the preferred model specification of sorghum prices

Multivariate tests [*p*-values]						
Test of normality		X^2 (12) = 28.991; p = 0.004				
Test of no autocorrelation	LM(1)	X^2 (36) = 48.318; p = 0.082				
Test of no autocorrelation	LM(2)	X^2 (36) = 55.127; p = 0.022				
Test of no ARCH	LM(1)	X^2 (441) = 454.993; p = 0.313				
Test of no ARCH	LM(2)	X^2 (882) = 977.444; p = 0.014				
Univariate tests						
	Gulu	**Jinja**	**Mbale**	**Soroti**	**World**	**Oil**
Normality (2) [*p*-value]	5.012 *(0.082)*	0.453 *(0.797)*	1.921 *(0.383)*	6.063 *(0.048)*	3.637 *(0.162)*	4.202 *(0.122)*
No ARCH (2) [*p*-value]	1.895 *(0.388)*	7.776 *(0.020)*	3.909 *(0.142)*	0.827 *(0.661)*	1.003 *(0.606)*	1.258 *(0.533)*
Skewness	-0.396	0.140	0.180	-0.557	-0.183	-0.210
Kurtosis	3.942	2.946	3.368	4.161	3.682	3.774

Figure 9: Constancy of the parameters of the sorghum prices. Test of Beta(t) = 'Known Beta' and test of constancy of the likelihood function, respectively, fluctuating around the 5 % critical value, indexed to 1.0





Appendix B – Rank determination of the sorghum sample

Table 12: Modulus of the characteristic roots of the companion matrix

p-r	R	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6
6	0	1.000	1.000	1.000	1.000	1.000	1.000
5	1	1.000	1.000	1.000	1.000	1.000	0.525
4	2	1.000	1.000	1.000	1.000	0.557	0.557
3	3	1.000	1.000	1.000	0.840	0.555	0.555
2	4	1.000	1.000	0.962	0.547	0.547	0.517
1	5	1.000	0.942	0. 811	0.550	0.550	0.524
0	6	0.932	0.932	0.924	0.560	0.560	0.557

Table 13: The unrestricted alpha matrix of the sorghum sample

	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	$\hat{\alpha}_4$	$\hat{\alpha}_5$	$\hat{\alpha}_6$
ΔGulu	-0.076 *(-0.793)*	-0.590 *(-2.531)*	-0.610 *(-2.668)*	0.111 *(1.721)*	0.084 *(0.459)*	0.351 *(2.031)*
ΔJinja	0.491 *(4.070)*	1.524 *(5.214)*	0.070 *(0.243)*	0.170 *(2.108)*	-0.278 *(-1.202)*	0.213 *(0.981)*
ΔMbale	0.620 *(6.053)*	-0.566 *(-2.281)*	-0.978 *(-4.016)*	-0.162 *(-2.367)*	-0.040 *(-0.202)*	0.010 *(0.052)*
ΔSoroti	-0.369 *(-4.418)*	0.534 *(2.641)*	-0.974 *(-4.903)*	-0.095 *(-1.695)*	-0.108 *(-0.677)*	0.089 *(0.591)*
ΔWorld	0.008 *(0.220)*	-0.096 *(-1.048)*	0.182 *(2.024)*	-0.045 *(-1.767)*	-0.066 *(-0.919)*	0.146 *(2.149)*
ΔOil	-0.016 *(-0.868)*	-0.108 *(-2.415)*	0.007 *(0.155)*	0.019 *(1.529)*	-0.100 *(-2.821)*	-0.011 *(-0.345)*

NB: *t*-values in parentheses.

Appendix C – Rank determination of the coffee samples

Table 14: Modulus of the characteristic roots of the companion matrix of the two coffee samples

p-r	r	Root 1	Root 2	Root 3	Root 4	Root 5	Root 6
First coffee sample							
6	0	1.000	1.000	1.000	0.756	0.756	0.629
5	1	1.000	1.000	0.786	0.786	0.776	0.776
4	2	1.000	0.920	0.775	0.775	0.749	0.749
3	3	0.930	0.880	0.784	0.784	0.779	0.779
Second coffee sample							
6	0	1.000	1.000	1.000	0.488	0.488	0.475
5	1	1.000	1.000	0.492	0.492	0.483	0.483
4	2	1.000	0.885	0.488	0.488	0.464	0.464
3	3	1.003	0.877	0.556	0.556	0.490	0.490

Table 15: Unrestricted alpha matrices of the two coffee samples

	First coffee sample			Second coffee sample		
	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$	$\hat{\alpha}_1$	$\hat{\alpha}_2$	$\hat{\alpha}_3$
ΔWorld	-1.446 *(-2.267)*	1.849 *(2.899)*	0.02 *(0.031)*	0.565 *(2.263)*	-0.531 *(-2.126)*	-0.176 *(-0.705)*
ΔUganda	-6.124 (-5.55)	0.346 *(0.313)*	0.024 *(0.022)*	0.65 *(2.109)*	-0.147 *(-0.478)*	-0.54 *(-1.753)*
ΔOil	0.154 *(1.259)*	0.026 *(0.216)*	0.175 (1.43)	-1.044 *(-4.117)*	-0.264 *(-1.042)*	-0.174 *(-0.685)*

Appendix D – Long-run structure of the sorghum sample

Accepted co-integrating relations in the sorghum analysis, with the world price included in the analysis.

$CI_{A.1}$: *(Gulu – (World + Oil)) + Jinja + 5*Mbale – 9*Soroti ~ I(0)*
$CI_{A.2}$: *(Jinja – (World + Oil)) – 5*Gulu – 6*Mbale + 14*Soroti ~ I(0)*
$CI_{A.3}$: *(Soroti – (World + Oil)) – Gulu + Jinja ~ I(0)*
$CI_{A.4}$: *(Gulu + Jinja – (World + Oil)) + 4*Mbale – 7*Soroti ~ I(0)*
$CI_{A.5}$: *(Jinja + Soroti – (World + Oil))– Gulu ~ I(0)*

Table 16: An over-identified long-run structure for the sorghum price structure

	Gulu	Jinja	Mbale	Soroti	World	Oil	Trend
$\hat{\alpha}_1$' :	1075.179 *(2.951)*	-740.266 *(-1.581)*	2034.373 *(4.271)*	1292.373 *(4.271)*	--	--	--
$\hat{\beta}_1$' :	--	0.000 *(7.548)*	-0.000 *(-7.548)*	0.000 *(7.548)*	--	-0.001 (-16.833)	1.000 *(NA)*
$\hat{\alpha}_2$' :	-0.240 *(-1.891)*	0.558 *(3.419)*	0.519 *(3.953)*	-0.659 *(-6.244)*	--	--	--
$\hat{\beta}_2$' :	−-0.148 *(-4.569)*	−-0.148 *(-4.569)*	−-0.541 (-12.226)	1.000 *(NA)*	--	0.148 *(4.569)*	--
$\hat{\alpha}_3$' :	0.177 *(1.991)*	-0.637 *(-5.565)*	-0.251 *(-2.723)*	-0.117 *(-1.579)*	--	--	--
$\hat{\beta}_3$' :	-1.104 *(-9.750)*	1.000 *(NA)*	0.055 *(0.516)*	1.000 *(NA)*	--	-1.000 *(NA)*	--
				***Π*-matrix**			
ΔGulu	-0.160 *(-1.712)*	0.399 *(3.588)*	-0.046 *(-0.568)*	0.123 *(1.033)*	--	-1.171 *(-3.541)*	1075.179 *(2.951)*
ΔJinja	0.621 *(5.160)*	-0.848 *(-5.935)*	-0.209 *(-1.993)*	-0.207 *(-1.353)*	--	1.379 *(3.246)*	-740.266 *(-1.581)*
ΔMbale	0.200 *(2.067)*	0.024 *(0.209)*	-0.646 *(-7.670)*	0.620 *(5.041)*	--	-1.484 *(-4.345)*	2034.010 *(5.404)*
ΔSoroti	0.227 *(2.916)*	0.204 *(2.211)*	0.126 *(1.869)*	-0.552 *(-5.590)*	--	-1.132 *(-4.122)*	1292.373 *(4.271)*
ΔWorld	--	--	--	--	--	--	--
ΔOil	--	--	--	--	--	--	--

Test of over-identifying restrictions: X^2 (12) = 17.166 accepted with a *p*-value of 0.143.

Appendix E – Output from the sorghum analysis

Table 17: Identifying long-run restrictions for sorghum (Bartlett-corrected sizes)

	Gulu	Jinja	Mbale	Soroti	World	Oil	Trend	$X^2_{0.95}(v)$	*p*-value
H_1 :	1.000 *(NA)*	0.801 *(3.230)*	3.160 *(7.772)*	-5.763 *(-11.695)*	--	1.000 *(NA)*	--	0.422	0.516
H_2 :	1.096 *(2.369)*	1.000 *(NA)*	3.855 *(7.669)*	-6.984 *(-10.376)*	--	-1.000 *(NA)*	--	0.580	0.446
H_3 :	--	0.705 *(8.200)*	1.000 *(NA)*	-1.418 *(-12.385)*	--	-1.000 *(NA)*	--	1.756	0.185
H_4 :	-0.790 *(-6.392)*	0.721 *(7.978)*	--	1.000 *(NA)*	--	-1.000 *(NA)*	--	3.833	0.050
H_5 :	1.000 *(NA)*	1.000 *(NA)*	1.000 *(NA)*	1.000 *(NA)*	--	-1.000 *(NA)*	13999	20.651	0.000
H_6 :	1.000 *(NA)*	1.000 *(NA)*	--	1.000 *(NA)*	--	-1.000 *(NA)*	--	20.154	0.000
H_7 :	0.001 *(4.681)*	-0.001 *(-6.099)*	-0.001 *(-6.099)*	-0.001 *(-6.099)*	--	-0.001 *(-6.099)*	1.000 *(NA)*	13.120	0.001
H_8 :	1.000 *(NA)*	9.581	1.000 *(NA)*	1.000 *(NA)*	--	-1.000 *(NA)*	50687	19.625	0.000
H_9 :	-1.000 *(NA)*	-1.000 *(NA)*	3.662	-6.422	--	1.000 *(NA)*	-649	0.171	0.679
H_{10} :	-1.000 *(NA)*	0.925	1.509	1.000 *(NA)*	--	1.000 *(NA)*	-3332	4.451	0.035
H_{11} :	-1.100	1.000 *(NA)*	0.079	1.000 *(NA)*	--	-1.000 *(NA)*	-307	5.105	0.024
H_{12} :	-2.223	1.978	1.000 *(NA)*	1.000 *(NA)*	--	-1.000 *(NA)*	-2338	5.799	0.016

Note: All tests are performed with and without the trend. None of the hypotheses are accepted if the remaining variables are restricted to zero. The world price is excluded for all relations, as discussed above. For the last four tests, normalization that enabled calculation of the standard errors was not possible.

Table 18: Sorghum: Investigation of the unrestricted Gamma matrix

	ΔGulu $_{t-1}$	ΔJinja $_{t-1}$	ΔMbale $_{t-1}$	ΔSoroti $_{t-1}$	ΔWorld $_{t-1}$	ΔOil $_{t-1}$
ΔGulu	-0.258 *(-2.838)*	-0.221 *(-2.683)*	-0.042 *(-0.536)*	-0.093 *(-0.862)*	-0.353 *(-1.245)*	0.573 *(0.952)*
ΔJinja	-0.134 *(-1.175)*	0.046 *(0.446)*	0.056 *(0.562)*	0.098 *(0.726)*	0.334 *(0.940)*	-0.771 *(-1.022)*
ΔMbale	0.048 *(0.499)*	0.200 *(2.313)*	-0.053 *(-0.635)*	-0.422 *(-3.704)*	0.137 (0.46)	-1.916 *(-3.018)*
ΔSoroti	0.071 *(0.917)*	-0.126 *(-1.806)*	-0.033 *(-0.491)*	0.03 *(0.327)*	0.208 *(0.863)*	-0.305 *(-0.596)*
ΔWorld	0.049 *(1.370)*	-0.036 *(-1.120)*	-0.018 *(-0.582)*	0.004 *(0.091)*	0.155 *(1.384)*	0.045 *(0.189)*
ΔOil	0.018 *(1.034)*	-0.021 *(-1.323)*	0.012 *(0.774)*	-0.007 *(-0.346)*	0.070 *(1.257)*	-0.103 *(-0.868)*

Table 19: Sorghum: Investigation of the restricted Gamma matrix

	ΔGulu $_{t-1}$	ΔJinja $_{t-1}$	ΔMbale $_{t-1}$	ΔSoroti $_{t-1}$	ΔWorld $_{t-1}$	ΔOil $_{t-1}$
ΔGulu	-0.230 *(-2.489)*	-0.234 *(-2.861)*	-0.040 *(-0.518)*	-0.094 *(-0.876)*	-0.401 *(-1.426)*	0.531 *(0.878)*
ΔJinja	-0.193 *(-1.629)*	0.057 *(0.547)*	0.030 *(0.306)*	0.113 *(0.821)*	0.567 *(1.572)*	-0.516 *(-0.663)*
ΔMbale	0.003 *(0.035)*	0.171 *(2.020)*	-0.038 *(-0.477)*	-0.442 *(-3.989)*	0.254 *(0.877)*	-1.573 *(-2.514)*
ΔSoroti	0.055 *(0.718)*	-0.142 *(-2.092)*	-0.013 *(-0.199)*	0.015 *(0.167)*	0.273 *(1.171)*	-0.087 *(-0.173)*
ΔWorld	0.025 *(0.659)*	0.023 *(0.673)*	-0.023 *(-0.714)*	0.016 *(0.366)*	0.178 *(1.542)*	0.184 *(0.737)*
ΔOil	0.012 *(0.617)*	-0.005 *(-0.281)*	0.020 *(1.263)*	0.007 *(0.330)*	0.059 *(1.020)*	-0.120 *(-0.960)*

Table 20: Sorghum: The restricted *C*-matrix

	$\hat{\varepsilon}_{Gulu}$	$\hat{\varepsilon}_{Jinja}$	$\hat{\varepsilon}_{Mbale}$	$\hat{\varepsilon}_{Soroti}$	$\hat{\varepsilon}_{World}$	$\hat{\varepsilon}_{Oil}$
ΔGulu	0.865 *(4.043)*	0.357 *(2.521)*	-0.213 *(-1.183)*	-0.180 *(-0.837)*	-0.440 *(-0.992)*	-1.949 *(-1.786)*
ΔJinja	0.334 (2.860)	0.138 *(1.783)*	-0.082 *(-0.837)*	-0.070 *(-0.592)*	0.011 *(0.045)*	1.773 *(2.972)*
ΔMbale	0.797 *(3.166)*	0.329 *(1.974)*	-0.196 *(-0.926)*	-0.166 *(-0.655)*	-0.640 *(-1.226)*	-5.067 *(-3.948)*
ΔSoroti	0.604 *(3.563)*	0.250 *(2.222)*	-0.149 *(-1.043)*	-0.126 *(-0.737)*	-0.417 *(-1.184)*	-2.879 *(-3.328)*
ΔWorld	0.032 *(0.329)*	0.013 *(0.205)*	-0.008 *(-0.096)*	-0.007 *(-0.068)*	1.224 *(6.161)*	0.245 *(0.502)*
ΔOil	0.028 *(0.868)*	0.011 *(0.541)*	-0.007 *(-0.254)*	-0.006 *(-0.180)*	0.046 *(0.692)*	0.768 *(4.749)*

Appendix F – Robustness check of the sorghum sample

Table 21 Sorghum: *C*-matrix and cross-correlations for a rank of four

	$\hat{\varepsilon}_{Gulu}$	$\hat{\varepsilon}_{Jinja}$	$\hat{\varepsilon}_{Mbale}$	$\hat{\varepsilon}_{Soroti}$	$\hat{\varepsilon}_{World}$	$\hat{\varepsilon}_{Oil}$
ΔGulu	1.339 *(2.041)*	0.204 *(0.884)*	-0.253 *(-0.701)*	-0.108 *(-0.269)*	2.700 *(1.030)*	-5.999 *(-1.267)*
ΔJinja	0.283 *(1.220)*	0.171 *(2.083)*	-0.032 *(-0.249)*	-0.127 *(-0.900)*	1.381 *(1.489)*	0.431 *(0.257)*
ΔMbale	1.058 *(2.068)*	0.099 *(0.548)*	-0.211 *(-0.749)*	-0.159 *(-0.510)*	1.736 *(0.849)*	-5.580 *(-1.511)*
ΔSoroti	0.824 *(2.055)*	0.110 *(0.779)*	-0.159 *(-0.718)*	-0.085 *(-0.347)*	1.563 *(0.975)*	-3.903 *(-1.348)*
ΔWorld	-0.235 *(-1.684)*	0.041 *(0.835)*	0.058 *(0.751)*	0.110 *(1.290)*	0.016 *(0.028)*	2.085 *(2.067)*
ΔOil	0.008 *(0.166)*	0.038 *(2.224)*	0.005 *(0.179)*	0.043 *(1.447)*	0.252 *(1.293)*	0.458 *(1.302)*

Table 22: Sorghum: *C*-matrix and cross-correlations for a rank of two

	$\hat{\varepsilon}_{Gulu}$	$\hat{\varepsilon}_{Jinja}$	$\hat{\varepsilon}_{Mbale}$	$\hat{\varepsilon}_{Soroti}$	$\hat{\varepsilon}_{World}$	$\hat{\varepsilon}_{Oil}$
ΔGulu	0.687 *(9.685)*	0.155 *(1.938)*	0.007 *(0.119)*	0.098 *(0.850)*	-0.437 *(-1.525)*	-0.729 *(-1.727)*
ΔJinja	0.299 *(4.555)*	0.231 *(3.131)*	-0.160 *(-2.981)*	-0.091 *(-0.856)*	0.313 *(1.182)*	1.734 *(4.444)*
ΔMbale	0.149 *(1.529)*	-0.102 *(-0.933)*	0.422 *(5.313)*	0.600 *(3.815)*	-0.113 *(-0.287)*	-1.388 *(-2.400)*
ΔSoroti	0.190 *(3.185)*	-0.012 *(-0.183)*	0.247 *(5.063)*	0.381 *(3.952)*	-0.065 *(-0.271)*	-0.555 *(-1.566)*
ΔWorld	0.000 *(0.007)*	0.055 *(1.071)*	-0.028 *(-0.742)*	0.051 *(0.694)*	1.233 *(6.706)*	0.076 *(0.279)*
ΔOil	-0.015 *(-0.985)*	0.040 *(2.383)*	0.007 *(0.533)*	0.037 *(1.538)*	0.072 *(1.197)*	0.729 *(8.199)*