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External Economic Shocks and Food Price Volatility in Rwanda: Evidence from the ARCH and GARCH Models

Sandrine UNEZEZA and Jean Baptiste HABYARIMANA

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Jönköping International Business School (JIBS),
Jönköping University, P.O. Box 1026,
SE-551 11 Jönköping, Sweden,
Web: http://www.ju.se/earp, E-mail: EARP@ju.se

Preface

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Editor: Almas Heshmati
Professor of Economics
Jönköping International Business School (JIBS),
Jönköping University, Room B5017,
P.O. Box 1026, SE-551 11 Jönköping, Sweden,
E-mail: Almas.Heshmati@ju.se

External Economic Shocks and Food Price Volatility in Rwanda: Evidence from the ARCH and GARCH models

Sandrine Unezeza[1] and Jean Baptiste Habyarimana[2]

[1]Corresponding author:
Department of Applied Statistics
School of Economics
University of Rwanda, Kigali, Rwanda,
E-mail: sunezeza@gmail.com

[2]Department of Economics
School of Economics
University of Rwanda, Kigali, Rwanda
E-mail: kradrimn@gmail.com

Abstract

This paper adopts and explains the use of autoregressive conditional heteroscedasticity (ARCH) and generalized autoregressive conditional heteroscedasticity (GARCH) models to investigate how variations in the price of crude oil in Rwanda and in the world market as an external economic shock affect the price of cereals in Rwanda's domestic market. Our empirical results show that cereal price series are linearly related to crude oil price series and that they suffer from a high relative variability. Price returns' analyses reveal that there is evidence of volatility in cereal price returns clustering from variations in the price of crude oil in both the domestic Rwandan market and the world market. ARCH and GARCH results demonstrate that volatility in the market price of cereals in Rwanda is strongly influenced by own past squared residuals and by past squared residuals in the price of crude oil in both domestic and world markets. Further, the scedastic functions reveal that upward movements in the price of crude oil in Rwanda lead to a period of high cereal prices (maize and wheat). To reduce inefficiencies in the domestic cereal distribution system while improving cereal market efficiency and ensuring food security, this paper suggests that trade policy in Rwanda should take into consideration the relationship that exists between the price of crude oil and the price of cereals. This paper also suggests that as there exists a negative relationship between the devaluation of the Rwandan currency and the price of crude oil in Rwanda, stabilizing the Rwandan franc will lead to stability in crude oil prices which will be a key factor in rendering the cereal distribution system in the country more efficient.

Keywords: External economic shock, food price volatility, ARCH and GARCH models.

JEL Classification Codes: C32; C53; E31; Q18;

1. Introduction

Food access, which is determined by food price stability among other things, plays an important role in ensuring food security in any country (Food and Agriculture Organization, 2006). Thus, variations in food market prices are linked to instability about food security where large and unexpected surges in food prices are inversely related to food security and poverty (Diaz-Bonilla and Ron, 2010; FAO, 2011; Ivanic and Martin, 2008). However, food price stability offers various benefits to consumers and producers because it is an important factor that helps economic agents to take effective investment, saving, production and consumption decisions (Grega, 2002). Among other things, variations in oil prices are one of the factors which can be linked to food price volatility in the domestic market (FAO, 2011).

Oil is considered as input for bridging food markets where it is used in the transport industry. Therefore, oil prices play a big role in the food distribution system in which the price of food transported from one market to another relates to the cost of transport (FAO, 2011). Further, the cost of transport depends on oil price levels. When oil prices increase in the world market they also increase in the domestic market depending on the level of domestic oil consumption. Thus, an increase in oil prices leads to an increase in the cost of transport which also affects food prices throughout the food distribution system. Second, when oil prices decrease in the world market, oil prices in the domestic market also decrease. Hence, variations in oil prices are among the factors that can distort the food distribution system and therefore lead to variations in cereal prices. For net oil importer countries, an effective food distribution system depends on the stability of oil prices in both domestic and world markets. This suggests that any oil price instability also causes inefficiencies in the food distribution systems in these countries either in international transport and domestic food distribution or in domestic food distribution alone. An ineffective food distribution system may result in domestic food market inefficiencies caused by abrupt changes in the cost of transport, leading also to unexpected food price variations in the domestic market (FAO, 2011). Therefore, in one way or another, food prices prevailing in domestic markets are linked to oil prices through the effect of oil price variations which cause food price variations through variations in the cost of transport. This shows that oil price volatility is one of the channels which results in food price volatility for both domestically produced foods and/or imported foods. However, it should be noted that oil prices do not directly affect food prices, but they are related in their variances.

The trade balance for staple commodities reveals that in addition to domestically produced cereals they are also among the food commodities mainly imported in Rwanda (MINAGRI et al., 2016). This shows that like domestic transport costs, international transport costs may have an influence on the price of cereals domestically traded in Rwanda. As Rwanda is a net importer of oil (MINIRENA et al., 2011), the effectiveness of its food distribution system depends on the stability of oil prices in both domestic and world markets. Consequently, food price variations in the Rwandan domestic market are probably related to variations in the price of oil in both domestic and world markets.

This paper investigates if this liaison exists between cereal price variations in the Rwandan domestic market and oil price variations in the Rwandan and world markets. We selected four highly traded and consumed cereals in Rwanda: maize, rice, wheat and sorghum (NISR, 2016). Linking our investigation and the food security situation in

Rwanda, the outcome of food price variations as a result of variations in oil prices is food security instability.

This paper has two main research objectives: first, to apply the ARCH and GARCH models to analyze the relationship between volatility in cereal prices in Rwanda and oil price variations in both the Rwandan and world markets. And second, to use scedastic functions to understand the liaison between cereal prices' conditional variances in Rwanda and oil price variations in the Rwandan and world markets. To achieve these objectives, this paper answers two main research questions. First, if there is evidence to conclude that variations observable in the prices of cereals in the domestic market in Rwanda are related to oil price variations in the Rwandan and world markets. And second, if high conditional variances in the prices of cereals in Rwanda are related to high oil price variations in both the Rwandan and world markets.

2. Literature review

2.1. Concepts and definitions

External economic shock

An economic shock is an event that produces a significant change within an economy despite occurring outside of it. Economic shocks are unpredictable and typically impact supply or demand throughout markets.[1] A shock is an unexpected event that can affect an economy positively or negatively. A shock can occur on either the demand side or the supply side: a demand side shock refers to an unexpected fall or increase in the demand for goods and services whereas a supply side shock refers to an unexpected fall or increase in the supply of goods and services that are available to consumer. Shocks can be endogenous or exogenous. Exogenous shocks mostly affect the poorest countries. Positive shocks do not offset negative ones partly because negative shocks have irreversible effects (Varangis et al., 2004).

A hike in oil prices is a well-known classic exogenous shock, which leads to petrol rationing, power rationing, recession and inflation.[2] As Rwanda is a net importer of oil, a shock in oil prices reverberates in its transport system because of which its food distribution system is also affected. There are resulting effects of this on transport costs and these variations may also cause variations in prices of commodities that use transport.

Price volatility

Price volatility has been defined as a variation from the price's average value over a measurement period. If a price varies a great deal from month to month, price volatility will be high, and conversely if the month to month variations are low, the value of volatility will also be low (Aizenman and Pinto, 2004). On the one hand, price volatility determines price fluctuations over time and shows the degree of the price spread. On the other hand, price stability can be observed in a situation where prices do not change much over time. This shows an absence of volatility and is usually preferable over price volatility (Aizenman and Pinto, 2004). Therefore, this leads us to conclude that all price

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[1] 'Economic Shock': http://www.investopedia.com/terms/e/economic-shock.asp#ixzz4aeCImbze

[2] http://www.businessstudiesalevel.co.uk/exogenous%20shocks.pdf

variations do not create problems. Prices with small variations are usually considered to have minor effects on consumer and producer behaviors. However, large variations are considered to have a major impact on the behaviors of both consumers and producers because they create uncertainty about future investment decisions for producers and render consumers' purchasing power unstable (Aizenman and Pinto, 2004; FAO, 2011; WFP, 2008).

Various authors have investigated price volatility to understand market segmentation and/ or integration and characterize how commodity price variations are interlinked commodity by commodity or how they are spatially related. They do this by analyzing how price variations in a given commodity can influence variations in the prices of other commodities or how two or more markets selling a given commodity may be related through the behavior of the price prevailing in each market. In addition, studies have also analyzed price variability to assess the impact of price volatility on market efficiency in food commodities and food security. First, high price volatilities in food commodities, increased food market inefficiencies; second high and positive price volatilities negatively affect households' purchasing power, and worse, households' food security; lastly, high and negative food price volatilities lead to improvements in households' purchasing power and then improvements in food security (Diaz-Bonilla and Ron, 2010; FAO, 2011).

The food distribution system

The food distribution system is a method of distributing or transporting food or drink from one place to another.[3] Food distribution is considered a sub-set of the food system, where food distribution systems vary from one location to another (FAO, 2011).[4] Consequently, inefficiencies in the food distribution system may result in food price volatility (Dillon and Barret, 2015). Apart from this, food price volatility observed in staple food commodities in particular is also influenced by crop yield instability as a result of climate variability, exchange rate volatility, variations in crude oil prices, food stock variability, export concentration, interest rate volatility and economic and policy reforms (FAO, 2011; Grega, 2002; ICTSD, 2009; Sarris, 2014; WB, 2013). Hence, variations in crude oil prices are cited among external economic shocks which can disturb food distribution systems as variations in crude oil prices are one of the channels through which there can be volatility in food prices.

2.2. Crude oil and cereal transport

Even though almost all developing countries depend on agriculture most of them are not self-sufficient in terms of cereal production (OECD, 2010). To compensate for the gap between their cereal production and demand, these countries mostly import cereals; this involves international transport and the costs related to it (Ivory, 1990; Veeman and Veeman, 1992). In addition, the amount of cereals consumed domestically in these countries is subject to domestic cereal distribution which requires shifting cereals from one domestic market to another involving domestic transport and the costs related to it.

[3] http://en.m.wikipedia.org/wiki/food_distribution
[4] http://www.fao.org/docrep/W0078e/w0078e04.htm

In our study we rely on the theory that variations in crude oil prices are related to cereal price volatility whereby a decrease in crude oil prices leads to a decline transport costs and then a decline in the prices of goods and services that are marketed (WB, 2013).[5] The same theory also confirms that in developing countries which are net importers of crude oil and which import a big part of their products, crude oil prices greatly determine the prices of goods and services in local markets (WB, 2013).[6] As Rwanda is among the net importers of crude oil, variability in crude oil prices in either the world market or in the domestic market is, in one way or another, transmitted to variability in cereal prices.

Taking maize as a primary staple food in the region (Ethiopia, Kenya, Tanzania, and Uganda), on average, a 1 per cent increase in global oil prices leads to 0.26 per cent increase in maize prices without considering the change in global maize prices. The dependency of local maize prices on global maize prices is 0.42 per cent, where a 1 per cent simultaneous increase in global oil prices and maize prices leads to a 0.68 per cent increase in local maize prices (Baltzer; 2013; Benson et al., 2008). To link the variations in the prices of staple food items to the distance within and between countries, the results of the Law-of-One-Price (LOP) tested after running level regressions in east Africa show that the border effect measured by the border dummy coefficient was considerable within a distance ranging from 300 to 6,000 km (Versaille, 2012). Cities that did not share a border showed higher departures from LOP compared to cities in adjacent countries (Versaille, 2012).

2.3. Literature on volatility modeling

A series of volatility models have been used in literature to characterize different variations in financial series. The most used volatility models can be grouped into seven important volatility models: latent volatility or (misleadingly) stochastic volatility models; implied volatility models; historical volatility models; scaling index volatility models; exponentially weighted moving average models; autoregressive conditional volatility models; and vector autoregressive models. In the stochastic volatility models, part of the changes in volatility are due to random shocks while in conditional volatility models, volatility δ_t, is time varying but not stochastic. Unlike conditional and stochastic volatility models, historical volatility (HIS) models build directly on realized volatility. HIS models simply involve calculating the variance (or standard deviation) of returns in the usual way over some historical period; this then becomes the volatility forecast for all future periods (Khan et al., 2008). There are two major types of HIS models: single state HIS models and the regime switching and transition exponential smoothing models (Khan et al., 2008). The implied volatility is the market's forecast of the volatility of underlying asset returns over the lifetime of an object. Exponentially weighted moving average is a simple extension of the historical volatility measure which allows more recent observations to have a stronger impact on the forecast of volatility than older data points. Under an exponential weighted moving average (EWMA) specification, the latest observation carries the largest weight, and weights associated with previous observations decline exponentially over time. Literature shows that EWMA has two advantages over the simple historical model: first, in practice volatility is likely to be affected more by recent events which carry more weight than events in the past. Second, the effect of a

[5] http://siteresources.worldbank.org/INTGEP/Resources/335315-1257200370513/04--Ch4--96-127.pdf
[6] http://siteresources.worldbank.org/INTGEP/Resources/335315-1257200370513/04--Ch4--96-127.pdf

single given observation on volatility declines at an exponential rate as weights attached to recent events fall (Brooks, 2008).

Autoregressive volatility models are a relatively simple example of the class of stochastic volatility specifications (Brooks, 2008). They obtain time series of observations on some volatility proxy. The non-linear models in widespread use in finance are the autoregressive conditionally heteroscedastic (ARCH) model; the generalized autoregressive conditionally heteroscedastic (GARCH) model; the asymmetric GARCH models (exponential generalized autoregressive conditionally heteroscedastic (EGARCH) model proposed by Nelson (1991) and the GJR model named after Glosten, Jagannathan and Runkle (Glosten et al., 1993); and the multivariate generalized autoregressive conditionally heteroscedastic (MGARCH) model. MGARCH models allow the conditional covariance matrix of the dependent variables to follow a flexible dynamic structure and allow the conditional mean to follow a vector autoregressive (VAR) structure (Engle and Kroner, 1995).

In the literature on volatility modeling that was reviewed it was found that two general classes of volatility models have been widely used. The first type formulates conditional variance directly as a function of observables. The second formulates models of volatility that are not functions purely of the observable; these are called latent volatility or (misleadingly) stochastic volatility models. Latent volatility models can be arbitrarily elaborated upon with structural breaks at a random time and with random amplitudes, multiple factors, jumps and fat-tailed shocks, fractals and multifractals and general types of non-linearities. Such models can typically be simulated but are difficult to estimate and forecast. This has led volatility modelers to frequently use the first type of models, conditional variance directly as a function of observables of which ARCH and GARCH are two main examples.

GARCH models are mainly characterized by the ARMA structure (Bollerslev, 1986; Drost and Nijman, 1993; Engle, 1982). For instance, when a process ε is GARCH (1, 1), ε^2 is ARMA (1, 1). This is the main reason for the widespread use of such models in financial econometrics. The second reason is that in econometrics these models perform well and are easy to estimate and forecast. Recent econometric contributions bridge the gap between these two types of modeling volatility by balancing theories behind volatility models that are a function of observables and those that are not a function of observables. Vector models were developed for this and the well know volatility models of this kind are the vector autoregressive (VAR) models, the vector error correction models and the Bayesian vector autoregressive with stochastic volatility models that allow an interpretation of a sudden large movement in the data as a result of drawing from a distribution with a randomly increased but unobserved variance (Uhlig, 1997).

Another important recent contribution to econometrics literature relates to improvements in volatility estimations. Most applications in literature show that one can use price range information to improve volatility estimation; this practice constitutes an important part in developing the VAR model for volatility.

3. Methodology and data

3.1. Conceptual framework

Oil prices can affect cereal prices through three main channels. First, higher oil prices can increase the costs of farm inputs such as chemical fertilizers, fuel tractors or pumps. Second, high global oil prices can stimulate market demand, for instance for corn, to convert into biofuel, thereby driving up the prices of some cereal commodities like maize in the global market which is then transmitted to the local market through trade linkages. Third, oil price increases can drive up transport costs which affect all traded commodities, cereals included (Beckman et al., 2013). The first and second channels are not of much importance for our paper which focuses on the third channel. As Figure 1 shows, cereal commodities mainly produced in Rwanda such as sorghum and maize are traded from rural areas to semi-urban areas and/or urban areas while cereal commodities that are not mainly produced in Rwanda are imported from outside the country to urban areas and then transported to semi-urban and/or rural areas. This circuit shows that both national and international transport may affect the prices of cereals in the Rwandan domestic market. Our paper does not focus on road infrastructure, the customs process and weather conditions but instead focuses on oil prices as one of the determinants of transport costs and observes how a shock in crude oil prices either in the world market or in the domestic market in Rwanda may lead to variations in cereal prices.

Insert Figure 1 about here

3.2. Empirical model

As this paper investigates how external economic shocks affect cereal price variations in Rwanda, this sub-section starts by differentiating 'oil prices as an external economic shock' and 'price volatility.' First, a shock is an unexpected event that can affect the economy positively or negatively and it can be endogenous or exogenous. Oil price hikes are a well-known classic exogenous shock, which leads to petrol rationing, power rationing, recession and inflation.[7] As Rwanda is a net importer of oil, a shock in oil prices reverberates in its transport system which also affects the food distribution system. The resulting effects are on the cost of transport variations which may also cause variations in prices of commodities like cereals that use transport. Second, price volatility has been defined as a variation from the price's average value over a measurement period (FAO, 2011). However, all price variations do not create problems. Prices with small variations are usually considered to have minor effects on consumer and producer behaviors. However, large variations are considered to have a major impact on both consumers and producers' behaviors because they create uncertainty about future investment decisions for producers and render consumers' purchasing power more unstable (FAO, 2011).

In addition, high price volatilities in food commodities, increase food market inefficiencies; high and positive price volatilities negatively affect households' purchasing power, and worse, households' food security. Further, high and negative food price volatilities lead to improvements in households' purchasing power and then improvements in food security (Diaz-Bonilla and Ron, 2010; FAO, 2011).

[7] http://www.businessstudiesalevel.co.uk/exogenous%20shocks.pdf

3.2.1. Descriptive statistics

To assess the variance in our variables we used the coefficient of variation, where CV is estimated as (Pannerselvam, 2004):

(1) $$CV = \frac{\delta}{\bar{X}}$$

where, CV is the coefficient of variation, δ is the standard deviation and $\bar{X}$ is the mean. To check variability in selected series, our paper assumes that any time series with CV greater than 10 per cent, records a high relative variability.

In addition to this, the Pearson product-moment correlation (*r*) was used to assess how each time series for food prices is related to each time series for oil prices either in the domestic or world markets. As in the conceptual framework, our paper explains that cereal prices and oil prices do not have a direct relationship, but an indirect relationship and the estimated *r* helps us to know the sign of the correlation among selected time series. For two variables x (oil price) and y (cereal price), *r* is estimated as (Pannerselvam, 2004):

(2) $$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}$$

3.2.2. Estimation of price return

Let Pt denote the oil price (either in the domestic or world market) or the price of a cereal commodity (maize, rice, sorghum or wheat) in time period t ϵ T= {0, 1, 2, …, 228}. Whereby, 228 observations are considered in this study which covers the period January 1998-December 2016. We computed the net price returns as in Martins-Filho et al., (2010), in which the net returns of the most recent period (Rt) is computed as:

(3) $\mathrm{R_t} = \frac{\mathrm{P_t - P_{t-1}}}{\mathrm{P_{t-1}}}$ and the log-returns computed as $r_t = 100[\ln(P_t) - \ln(P_{t-1})]$

The estimated log-returns are used to assess volatility clustering from the series of crude oil price returns (either domestic or world market) to series of cereal price returns (maize, rice, sorghum and wheat).

3.2.3. The ARCH and GARCH models

This paper investigates how external economic shocks affect cereal price variations in Rwanda. Literature on volatility modeling demonstrates that two general classes of volatility models are widely used (Bollerslev, 1986; Brooks, 2008; Engle, 1982; Khan et al., 2008; Uhlig, 1997). The first type formulates conditional variance directly as a function of observables. The second general class formulates models of volatility that are not functions purely of observables; these are called latent volatility or (misleadingly) stochastic volatility models. Our paper uses the first class and mobilizes and explains the application of ARCH and GARCH models to investigate how cereal price variations relate to crude oil prices in both domestic and world markets.

3.2.3.1. ARCH model's specification

Traditionally, heteroscedasticity and autocorrelation have been considered major problems in time series. Working on financial markets, Engle (1982) showed that large and small errors tend to occur in clusters such as exchange rates and stock market returns. To look at time heteroscedasticity in time series data, Engle proposed ARCH. The ARCH specification helps focus on the mean and the variance of the time series which are useful when we want to understand the magnitude of volatility in time series data.

Consider the following model (Engle, 1982):

(4) $$Y_t = \rho Y_{t-1} + \beta X + \varepsilon_t$$

The ARCH model is often simplified as:

(5) $$Y_t = \rho Y_{t-1} + \beta X + \varepsilon_t \qquad \varepsilon_t \sim (0, \sigma_t^2)$$

where $$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \dots + \alpha_p \varepsilon_{t-p}^2$$

where, $\sigma^2{}_t$ is the conditional disturbance variance.

3.2.3.2. GARCH model's specification

The main constraint in using the ARCH model is that the α_i parameters have to be positive. Most of the times the estimation produces negative estimates of α_i. Bollerslev (1986) solved this problem by proposing GARCH. In this model, the autoregression (AR) process (ARCH model) is turned into an autoregressive moving average (ARMA) process by adding a moving average process. The GARCH (p, q) model, where p is the order of the GARCH terms σ^2 and q is the order of the ARCH terms ε^2, is given by Bollerslev (1986) as:

(6) $$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \dots + \alpha_q \varepsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + \dots + \beta_p \sigma_{t-p}^2$$

(7) $$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-i}^2$$

Equation (7) clearly shows that the value of the conditional disturbance variance depends on both the past values of the shocks and its own past values.

3.3. Data sources and description

This study relies on secondary data. The main cereals selected are rice, maize, sorghum and wheat. The sample period covered is 1998 to 2016 or 216 months. Monthly information on prices of cereals was sourced from the National Institute of Statistics of Rwanda and that on crude oil prices from the National Bank of Rwanda. Apart from this data, this study also used the consumer price index sourced from the National Institute of Statistics of Rwanda and the world food price index sourced from the Food and Agricultural Organization's webpage. As the collected cereal prices and crude oil prices in the domestic market were in the local currency (Rwandan francs), this study used monthly exchange rates RWF/USD to convert all the prices to USD. Daily exchange rates were sourced from the National Bank of Rwanda, from which we estimated the average monthly exchange rates. To standardize the original monthly prices of crude oil in the domestic market expressed in RWF/liters with the price of crude oil in the world market expressed in USD/barrel, we converted original monthly prices of crude oil in the domestic market in USD/barrel, where 159 liters = 1 barrel. Our study also used the GDP deflator to correct inflation from gathered cereal and crude oil prices. The GDP deflector was sourced from the National Institute of Statistics of Rwanda.

4. Findings and discussion

4.1. Measuring variations in the prices of cereals and crude oil

Information about cereal price variability demonstrates that the spread of prices was higher in sorghum (CV = 40 per cent). Although, variability in the price of crude oil in both the Rwandan and world markets seems to be the same (CV=56 per cent), but the high interquartile range which is also a measurement of variability like CV demonstrates that high variability in crude oil prices was observable in the Rwandan market as compared to the world market. This is because the price of oil in Rwanda was higher even when crude oil prices decreased in the world market. This can be explained by the inverse relationship between crude oil prices and the devaluation of the Rwandan currency. Being a net importer of crude oil, the devaluation of the Rwandan currency vis-à-vis USD which is used for importing by Rwanda rendered the import of crude oil more expensive. As we said in our methodology that any time series with CV greater than 10 per cent has a high relative variability, our results in Table 1 reveal that all analyzed time series suffered from high relative variability. In addition, the correlation coefficients between the price of selected cereals and the price of crude oil showed the existence of a high and positive correlation between the price of cereals and the price of crude oil in the domestic market when compared to the effect of crude oil prices in the world market. This was expected as we considered the food distribution system in a country (Rwanda), which is a net importer of crude oil. The correlation matrix shows one exception, where the correlation between the price of maize and that of crude oil is the same in both the Rwandan market and the world market at 53 per cent and 51 per cent respectively.

Insert Table 1 about here

4.2. An analysis of cereals and crude oil price returns

As can be seen in Figures 2 and 3, the price returns series show random and rapid changes. Therefore, technically they are said to be volatile. The observed volatility seems to change over time and high volatility is observable in cereal commodities as compared to crude oil prices. Although there was cereal price volatility in 1998-2005, much more volatility was observed in 2006-10. Even though Figure 2 demonstrates that the price of crude oil in the world market experienced positive and negative changes it also shows that changes in the domestic price of crude oil were the most positive in 1998-2016. This may explain the upward movements in cereal prices experienced in this period (NISR, 2017). These movements may be linked to the positive changes in the price of crude oil in the domestic market which resulted in positive changes in transport costs. From the descriptive statistics in Table 1 and price returns in Figures 2 and 3, it is clearly observable that there is evidence of cereal price volatility clustering from variations in the price of crude oil in both the Rwandan and world markets to variations in the prices of selected cereals. This could be a good indication for applying ARCH and GARCH to handle this volatility clustering from crude oil prices to cereal prices.

Insert Figure 2 about here

Insert Figure 3 about here

4.2. ARCH and GARCH estimates

The results in Table 2 for the unit-root test show that in level all series appear to be non-stationary but they appear to be stationary in the first differences which implies that all series are integrated of order one, denoted by I(1). This suggests using estimated price returns as shown in Figures 2 and 3 for estimating ARCH and GARCH models to investigate conditional volatility over January 1998-December 2016.

First, by estimating how conditional variances in crude oil prices in the Rwandan domestic market and the world market affect variations in the price of rice in the Rwandan domestic market, the results in Table 2 show that the estimated coefficient of crude oil prices in the domestic market was positive and statistically significant at the 5 per cent level of significance. This suggests that variations in the price of rice in the domestic market were positively related to variations in the price of crude oil in the domestic market. This result predicts that positive changes in crude oil prices in Rwanda lead to positive changes in the price of rice in the domestic market. Second, by estimating how conditional variances in crude oil prices in the domestic and world markets affect variations in the price of maize in the domestic market, Table 2 demonstrates that the estimated coefficients of crude oil prices in both the domestic and world markets are not statistically significant at the 10 per cent, 5 per cent and 1 per cent levels of significance. Third, by estimating how conditional variances in crude oil prices in the domestic and world markets affect variations in the price of sorghum in the domestic market, Table 2 reveals that the estimated coefficient of crude oil prices in the domestic market was positive and statistically significant at the 10 per cent level of significance while it was negative and statistically significant at the 5 per cent level of significance for crude oil prices in the world market.

These results predict that positive changes in crude oil prices in Rwanda and in the world market respectively lead to positive and negative changes in the price of sorghum in the domestic market in Rwanda. Fourth, by estimating how conditional variances in crude oil prices in the domestic and world markets affect variations in the price of wheat in the domestic market, Table 2 also demonstrates that the estimated coefficient of crude oil prices in the domestic market was positive and statistically significant at the 5 per cent level of significance. This result predicts that positive changes in crude oil prices in Rwanda lead to positive changes in the price of wheat in the domestic market.

The results in Table 2 show that positive changes in the price of crude oil in Rwanda may result in food distribution inefficiencies likely to cause positive changes in the prices of rice, sorghum and wheat in the country. However, positive changes in the price of crude oil in the world market led to food distribution inefficiencies which were able to cause negative changes in the price of sorghum. On average, a 1 per cent increase in the price of crude oil in Rwanda led to a 0.14 per cent, 0.25 per cent and 0.14 per cent increase in the price of rice, sorghum and wheat respectively. As Rwanda is a net importer of crude oil, our paper's empirical findings show that positive variations in the price of crude oil in Rwanda are, in one way or another, translated into positive cereal price volatility mainly in rice, sorghum and wheat prices. These results are supported by the fact that a decrease in crude oil prices leads to a decline in transport costs and then a decline in the prices of goods and services and vice-versa (WB, 2013)[8] and second by the factor that variations in the prices of crude oil can cause inefficiencies in the food distribution system which may result in food price volatility (FAO, 2011; Grega, 2002; Sarris, 2014; WB, 2013). However, positive variations in the price of crude oil in the world market are, in one way or another, translated into negative sorghum price volatility, whereby a 1 per cent increase in the price of crude oil in the world market led to a 0.13 per cent decrease in the price of sorghum. This may be explained by the fact that sorghum has been marginalized by main agricultural and food security policies in the country (MINAGRI, 2011) resulting in low domestic consumption and high sorghum exports. Therefore, when the price of crude oil in the world market increases it becomes expensive to export the domestically produced sorghum leading to lower sorghum prices in the domestic market as the stock of sorghum increases while domestic consumption is lower.

The results in Table 2 show that the price of maize in Rwanda does not seem to be influenced by crude oil price variations. This may be explained by the fact that the biggest share of maize (79.7 per cent) domestically produced is auto-consumed by households (NISR, 2016). This suggests that only a small quantity of domestically produced maize (approximately 20.3 per cent) becomes a part of the food distribution system. This is an insignificant amount to be affected by variations in the price of crude oil.

Table 2 also demonstrate that for all the four selected cereal series, the absolute sum of coefficient for crude oil prices in the Rwanda domestic market and that in the world market is less than 1 which indicates a finite variance in the prices of rice, maize, sorghum and wheat in the domestic market in Rwanda and the price of crude oil in both the domestic and world markets.

Insert Table 2 about here

4.6. Estimates of scedastic functions

Disentangled cereal conditional variances from the ARCH model using scedastic functions demonstrates that for the prices of wheat, rice and maize, conditional variances peaked between 2009-16; this is a period which corresponds to surges in the price of crude oil in the Rwanda domestic market (Figure 4). This implies that upward movements in the price of crude oil in the domestic market in Rwanda led to a period of high price volatility in wheat, maize and rice. This may have resulted from the fact that compared to the price of sorghum, where conditional variances peaked during the period of low crude oil prices, the other three cereal commodities (maize, sorghum and wheat) were the most traded food commodities among food security crops in Rwanda. Food security crops selected for Rwanda include rice, maize, wheat, Irish potatoes, beans, cassava, banana and soybean (MINAGRI, 2011). Therefore, the exclusion of sorghum from among food security crops resulted in its low tradability and may explain the behavior of its conditional variances as their high peaks corresponded with periods of

[8] http://siteresources.worldbank.org/INTGEP/Resources/335315-1257200370513/04--Ch4--96-127.pdf

low crude oil prices. This was expected as maize, rice and wheat are highly traded in Rwanda and are subject to transport costs throughout the food distribution system.

Insert Figure 4 about here

5. Conclusion and policy implications

This paper adopted autoregressive conditional heteroscedasticity (ARCH) and generalized autoregressive conditional heteroscedasticity (GARCH) models as external economic shocks to investigate how variations in the price of crude oil in Rwandan and in world markets affect cereal prices in the domestic market in Rwanda. The main findings of this paper show that, on average, a 1 per cent increase in the price of crude oil in Rwanda led to a 0.14 per cent, 0.25 per cent and 0.14 per cent increase in the prices of rice, sorghum and wheat respectively. However, a 1 per cent increase in the price of crude oil in the world market led to a 0.13 per cent decrease in the price of sorghum. The other main findings of this paper also show that: (i) volatility in the market price of rice in the Rwandan market was strongly influenced by own past squared residuals (13 per cent) and by past squared residuals in the price of crude oil in both the domestic and world markets (7 per cent); (ii) volatility in the market price of maize in the Rwandan market was strongly influenced by own past squared residuals (25 per cent); (iii) volatility in the market price of sorghum in the Rwandan market was strongly influenced by own past squared residuals (35 per cent); and (iv) volatility in the market price of wheat in the Rwandan market was strongly influenced by own past squared residuals (32 per cent).

Two policy implications flow from the main results of this paper. First, it is very important for policymakers to recognize the relationship between the price of cereals and the price of crude oil because this can provide us with new thoughts about reducing inefficiencies in the domestic cereal distribution system. Reducing inefficiencies which may hamper the cereal distribution system will help in improving the cereal market's efficiency and integration in Rwanda and thus lead to food security through easy access to cereal commodities or cereal products. Second, there is evidence of volatility in cereal price returns clustering from variations in crude oil prices in both the domestic Rwandan market and the world market. Rwanda being a net importer of crude oil, economic reforms in Rwanda should focus on stabilizing the value of the Rwandan franc vis-à-vis USD. This may result in crude oil price stability in Rwanda. Thereafter, crude oil price stability will be a key factor in improving the effectiveness of the cereal distribution system, the efficiency of the cereal market and food access and acquisition in the country.

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Table 1: Summary of descriptive statistics

		Correlation		Variability measures	
		PCOR	PCOW	CV	iqr
Price of crude oil-Rwanda	PCOR	1.00		0.56	151.23
Price of crude oil-world	PCOW	0.80	1.00	0.56	59.78
Price of rice	PR	0.86	0.55	0.36	0.53
Price of maize	PM	0.53	0.51	0.29	0.12
Price of sorghum	PS	0.83	0.57	0.40	0.24
Price of wheat	PW	0.66	0.37	0.27	0.29

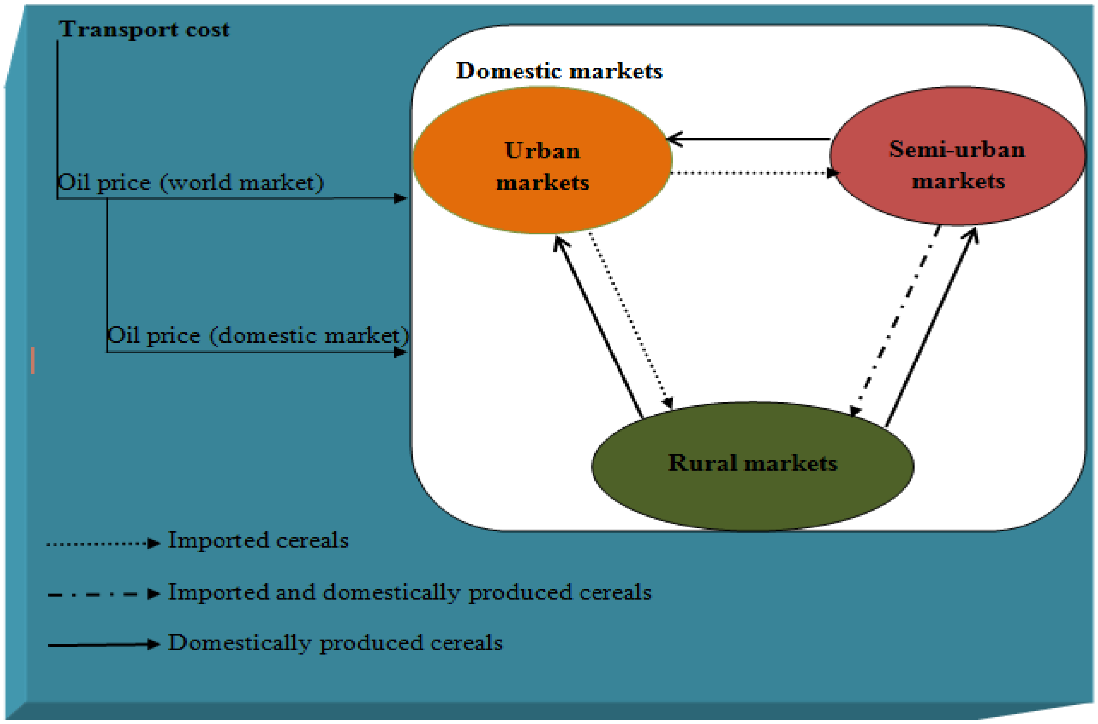
cv: coefficient of variation; p50: median; iqr: interquartile range

Table 2: ARCH and GARCH summary results

Variable	Crude oil price/ Rwanda	Crude oil price/ world	Rice price	Maize price	Sorghum price	Wheat price
Crude oil price/Rwanda			0.14^{**}	-0.09	0.25^{*}	0.14^{**}
			(0.06)	(0.13)	(0.14)	(0.06)
Crude oil price/world			-0.01	-0.08	-0.13^{**}	-0.01
			(0.02)	(0.06)	(0.06)	(0.03)
ARCH effect			0.13^{***}	0.25^{**}	0.35^{***}	0.32^{***}
			(0.04)	(0.11)	(0.12)	(0.08)
GARCH effect			0.07^{***}	-0.03	-0.06	0.02
			(0.16)	(0.27)	(0.13)	(0.20)
Constant			2.94	47.00	40.88^{***}	21.06^{***}
			(2.30)	(15.30)	(9.39)	(5.51)
Number of obs.			227	227	227	227
Wald chi2 (2)			6.04^{**}	2.55	7.59^{**}	4.66^{*}
Log likelihood			-638.27	-777.94	-769.60	-702.54
ADF test (data in level)	-1.08	-1.60	0.02	-2.42	-1.26	-1.75
ADF test (price returns)	-15.40^{***}	-11.61^{***}	-13.33^{***}	-9.96^{***}	-10.12^{***}	-17.25^{***}

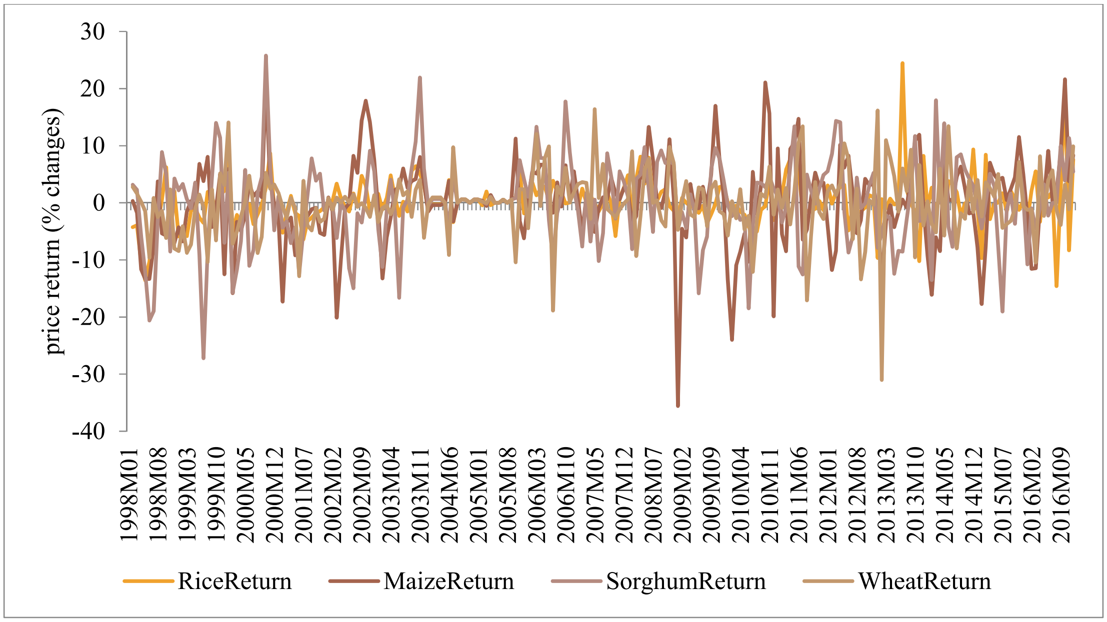
Figures in brackets are standard errors; *, **, *** indicate 10%, 5%, and 1% significance levels respectively. ADF test: augmented dickey-fuller (ADF) test for unit root.

Figure 1: Cereal transport system



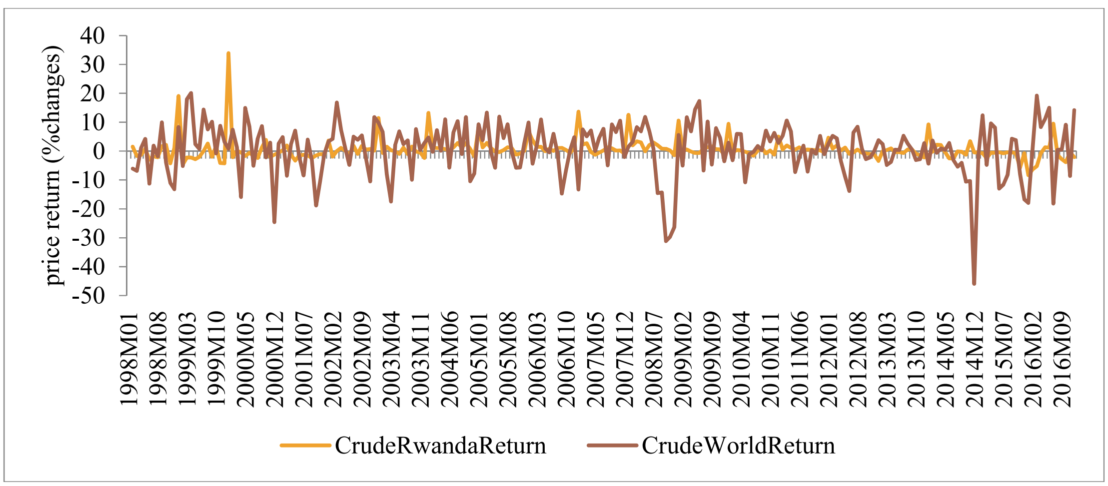
Source: Author's designed food distribution system.

Figure 2: Cereal price returns



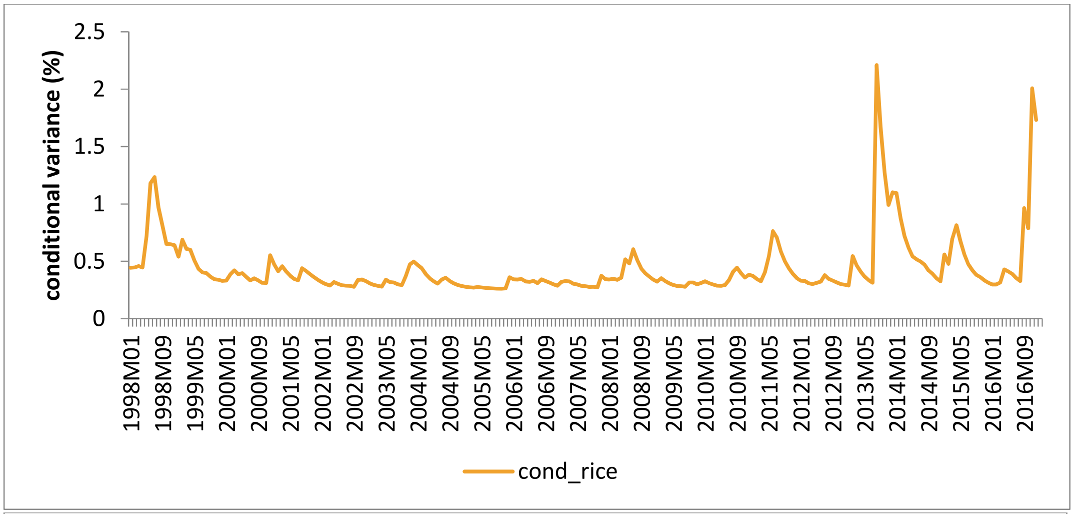
Source: Author's own computations.

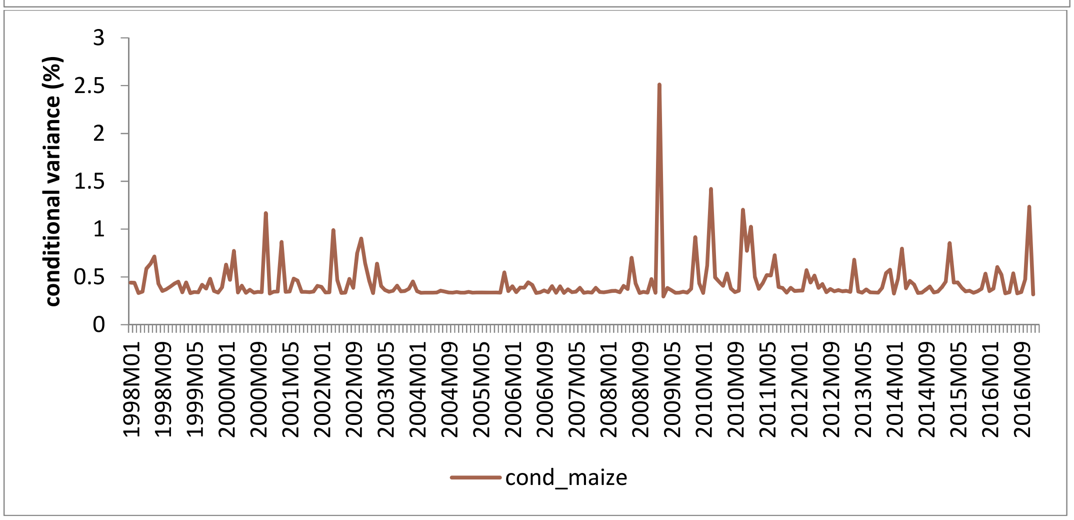
Figure 3: Crude oil price returns

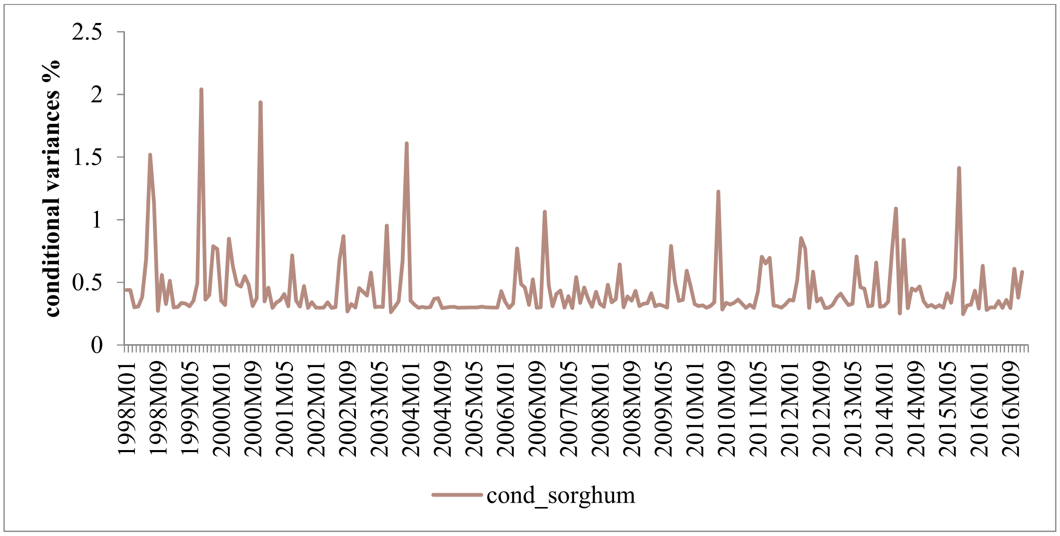


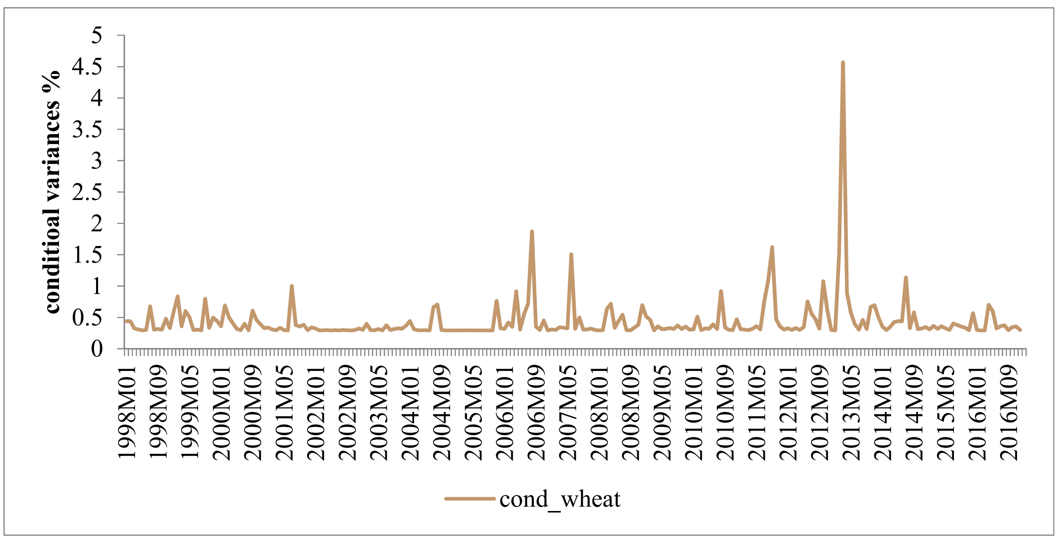
Source: Author's own computations.

Figure 4: Conditional variances for cereals









Source: Author’s own computations.

Note: Conditional variances presented in this figure are measured as percentage of the total conditional variances ever experienced from January 1998-December 2016.