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Modeling price transmission and volatility spillover in the Slovenian wheat market

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Abstract.

Interdependence between first and second moments of producer and consumer wheat prices in Slovenia is assessed. A joint estimation of a threshold vector error and MGARCH models with exogenous variables in the conditional mean and conditional covariance equations are applied for such purpose. Results indicate that price-level adjustments mainly favor retailers by increasing their marketing margins. Important second-moment interactions are also identified. Increases in international wheat stocks reduce producer prices, while higher interest rates increase their instability.

Keywords: Volatility, threshold model, MGARCH model

JEL codes: C22, Q11

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1. Introduction

Over the last decade, significant changes in world agricultural commodity prices have been observed. Important increases were registered from the beginning of 2006, reaching record levels by mid of 2008. Prices dramatically declined during the second half of 2008 and partially recovered after the second half of 2009, peaking again in 2011. These changes in global food prices have been accompanied by increased food price volatility (Sumner, 2009; Rapsomanikis, 2011; Serra, 2011). The outbreak of the global biofuel market, different weather effects involving substantial changes in global production, increased speculation in agricultural commodity futures markets, among other causes, have been considered as the driving factors. Interest in studying commodity prices has thus been renewed. A number of empirical studies have analyzed price-level linkages and patterns of price transmission along the food marketing chain (Reziti and Panagopoulos, 2008; Hassouneh et al., 2010). However, food price volatility has received much less research interest. A few notable exceptions are reviewed in this paper.

Buguk et al. (2003) study price volatility spillovers along the US catfish supply chain using an Exponential Generalized Autoregressive Conditional Heteroskedasticity (EGARCH) model. They find strong evidence of unidirectional volatility flows down the supply chain. The analysis by Apergis and Rezitis (2003) examines volatility spillover effects across agricultural input, agricultural output and retail food prices in Greece. They utilize a Vector Error Correction Model (VECM) specification to generate the error terms that are then modeled through a multivariate GARCH (MGARCH) process and find evidence of second-moment interactions among the markets considered. Rezitis and Stavropoulos (2011) assess nonlinear price-level behavior and price volatility interactions among producer and consumer broiler markets in Greece. A threshold VECM (TVECM) and two MGARCH models are separately estimated for such purpose. Evidence of both producer and consumer price-level adjustments to long-run disequilibriums is found. MGARCH results provide *significant* evidence of *volatility persistence* in producer and consumer markets. Serra (2011) investigates the impacts of the BSE crisis on the transmission of price instability along the Spanish beef marketing chain. A Smooth Transition Conditional Correlation (STCC)-GARCH model is applied. She finds evidence of different price volatility behavior under different market conditions.

A literature review on the subject shows that analyses assessing price volatility along the food marketing chain are very scarce and that have rarely allowed for nonlinearities in price behavior. This is in sharp contrast with the very relevant literature studying first-moment price dependencies along food markets, that has provided ample evidence of the need to allow for nonlinearities in price patterns (Meyer and von Cramon-Taubadel, 2004; Frey and Manera, 2007). Failure to correctly capture price-level behavior may lead to failure to soundly assess the second moment of the price distribution. To overcome this shortcoming, we study price dependencies between producer and consumer markets for wheat in Slovenia, by jointly estimating a nonlinear TVECM and MGARCH models.

Prices at a certain level of the food marketing chain are likely to depend not only on prices at other market levels, but also on other possible exogenous variables such as macroeconomic conditions or stock levels (Wright, 2011; Serra and Gil, 2012). The economic theory of storage indicates that commodity prices should depend on the level of stocks. Many empirical analyses have considered stocks to study commodity price dynamics and have found evidence of a strong relationship between stocks and price behaviour (Shively, 1996; Kim and Chavas, 2002; Balcombe, 2011; Stigler and Prakash, 2011). Interest rates have been also found to be relevant to explain food price dynamics by Kim and Chavas (2002), Frankel (2006) and Serra and Gil (2012). Other macroeconomic indicators including exchange rates have been also considered to study price fluctuations (Headey and Fan, 2008; Baffes and Haniotis, 2010; Bakucs et al., 2012). In the case of Slovenia, exchange rate may not be relevant due to the importance of intra-community trade of food products. According to the Statistical Office of the Republic of Slovenia (SORS, 2013), the quantity of total wheat imported into Slovenia from the EU member states reached 95.9% in 2011.

Our analysis allows for the influence of international wheat stocks-to-use ratio, as well as the Slovenian interest rates.[1] To our knowledge, this is the first price transmission along the food marketing chain analysis to allow for the influence of exogenous variables to explain both price levels and their volatility, which represents another contribution of our paper to the existing research.

The rest of paper is organized as follows. Section 2 presents an overview of the wheat sector in Slovenia. After describing both threshold and MGARCH techniques in section 3, in section 4 we present the results of the empirical application. Finally, the paper ends with the concluding remarks section.

[1] Other exogenous variables were considered, but not found to be statistically significant.

2. Wheat sector in Slovenia

Wheat production in Slovenia is mainly on small and medium-sized family farms and a few large commercial enterprises. The number of farms in wheat production declined between the two agricultural censuses from 30.9 thousand in 2000 to 18.5 thousand in 2010.[2] While the wheat area declined from 38.2 thousand ha in 2000 to 31.7 thousand ha in 2010, the area per farm increased from 1.24 ha to 1.71 ha. This suggests an increase in average wheat farm size and concentration of wheat production on a smaller number of farms. Most wheat is produced in the Eastern part of Slovenia. Wheat is the second most important field crop in Slovenia after maize, which is largely used for animal feed. However, wheat is the most important directly marketed field crop from farmers. The area harvested, yields and wheat production vary from year to year (SORS, 2012a). In particular, harvested areas tend to decline, yields tend to increase, and wheat production remains at similar levels. In 2011, Slovenia imported 225.6 thousand tons of wheat with an increase of 28.2% with respect to 2010. Variations in wheat imports are associated with variations in domestic production and consumption. Since the Slovenian adhesion to the Euro zone in 2004, almost all wheat is imported from the EU countries.

Human consumption (e.g. flour, bread and similar bakery products) is the most relevant wheat demand source. Average wheat consumption per capita is still above 70 kg. Most wheat is purchased during the main harvesting period in July when producer price is usually the lowest. Producer prices vary over time and wheat producers are taking a substantial part of the risks in the wheat supply chain. Assessing wheat price patterns in Slovenia is challenging research given the relevance of wheat price for producer revenues and for wheat flour-bread costs as well as for livestock feed in association with maize prices.

The relevance of wheat production over the whole agricultural sector in Slovenia can be appreciated from its importance in agricultural output. In 2011, cereals represented 9% of agricultural output and 5% of the value of marketed agricultural products. Wheat represented 3% of this value. Wheat plays crucial role for field crop farmers, particularly in remote, less developed Eastern part of Slovenia.

In 2010, 12.6% of annual average household expenditures were allocated to food, being bread and cereal expenses on the order of 2.4%. Since wheat is the main ingredient in bread and cereal

[2] Unless otherwise indicated, the information presented in this section was obtained from SORS (2013).

consumption, wheat represented around 20% of household expenditures on food. These figures clearly indicate crucial importance of wheat price for field crop farm revenues and for more equitable regional farm development. On the other hand, wheat price has relevant influence on food expenditures and food consumption, particularly for those consumers with lower incomes. Thus wheat market developments might play important role for economically sustainable development of field crop farming, food safety for vulnerable groups of consumers, and regional development of remote and less developed areas.

3. Methods

To assess price transmission and volatility spillovers within the Slovenian wheat market, we rely on a bivariate GARCH specification. As is well known, MGARCH models consist of two sub-models: the conditional mean and the conditional covariance models. Misspecifications in the conditional mean model will translate into biased second-moment dependency estimates. As mentioned above, previous literature on price time series data has provided ample evidence of non-linear price level transmission among related markets. The conditional mean model is thus specified as a TVECM that allows for price behavior change depending on market conditions. The economic theory of storage indicates that prices should depend on the level of stocks. The influence of world wheat inventories on the first moment of prices is considered, by incorporating world wheat stocks-to-use ratio in the mean price equations.[3] Since Slovenia is considered as a net importer of wheat, we expect that an increase in the international wheat stocks-to-use ratio will cause a market price decline. A one-threshold, two-regime bivariate TVECM can be expressed as follows:

$$\Delta P_t = \begin{cases} \alpha_1 + \alpha_{1,P} v_{t-1} + \sum_{i=1}^{n} \alpha_{1,i} \Delta P_{t-i} + \lambda_1 \Delta s_{t-i} + u_{1,t} & if \quad v_{t-d} \le c \\ \alpha_2 + \alpha_{2,P} v_{t-1} + \sum_{i=1}^{n} \alpha_{2,i} \Delta P_{t-i} + \lambda_2 \Delta s_{t-i} + u_{2,t} & if \quad v_{t-d} > c \end{cases} \tag{1}$$

[3] Other explanatory variables, including interest rate, were also considered, but not found to be statistically significant.

where $P_t = (P_{Pr,t}\ P_{Co,t})$ is the vector of producer and consumer prices being analyzed, respectively. s is a stocks-to-use ratio variable. $\alpha_{(m)}, \alpha_{(m),i}$, $m = 1, 2$ are vectors of parameters that capture short-run dynamic price responses and $\lambda_{(m)}$ measure the short-run impacts of the exogenous variable on price behaviour. $\alpha_{(m),P}$ are the adjustment parameters that measure the response of prices to deviations from the long-run equilibrium, $v_{t-1} = \alpha + P_{Pr,t-1} - \beta P_{Co,t-1}$ is the lagged error correction term derived from the cointegration relationship. $u_{(m),t}$ are the residuals of the conditional mean model, c is the threshold that delineates the different regimes and v_{t-d} represents the variable that triggers threshold behaviour. In price transmission analysis v_{t-d} is usually specified as the lagged value of the error correction term, v_{t-1}.

In order to estimate the threshold parameter, c, a grid search is applied. The threshold is searched over the values of the threshold variable and the search is restricted to ensure an adequate number of observations in each regime. The grid search minimizes the log determinant of the variance-covariance matrix of the residuals of the TVECMs, which is analogous to maximizing a likelihood function. To test for the significance of the differences in parameters across the relative regimes in a TVECM, a sup-LR statistic developed by Hansen and Seo (2002) is used. This test compares the fit of a linear VECM with the fit of the TVECM. The sup-LR statistic has a non-standard distribution because the threshold parameters are not identified under the null hypothesis. Hence, to calculate the p-value of the sup-LR statistic, bootstrapping techniques developed by Hansen and Seo (2002) are used. In our empirical model, a total of 1,000 simulations are run.

To examine volatility spillovers among producer and consumer markets, a bivariate Baba–Engle–Kraft–Kroner (BEKK) model is used to represent the conditional covariance model (Engle and Kroner, 1995):

$$H_t = CC' + A' u_{t-1} u'_{t-1} A + B' H_{t-1} B \qquad (2)$$

where H_t is a 2 × 2 conditional variance-covariance matrix. Matrix A (2 × 2) depicts the effects of lagged shocks on current price volatility, B (2×2) represents the influence of past volatility on current conditional variances, and C is a 2 × 2 lower triangular matrix. The influence of exogenous variables on price volatility can be allowed for through matrix C in (2) (Moschini and Myers, 2002; Serra and Gil; 2012). In our paper $c_{ij} = i_t \delta_{ij}$, where $i_t = (1, i_1)$, being i_1 the interest rate considered as an exogenous variable influencing price volatility, and δ_{ij} a parameter vector.[4]

A complete representation of a bivariate BEKK-GARCH model can be expressed as follows:

$$\begin{pmatrix} h_{11,t} & h_{12,t} \\ h_{12,t} & h_{22,t} \end{pmatrix} = \left[\begin{pmatrix} c_{111} & 0 \\ c_{211} & c_{221} \end{pmatrix} + \begin{pmatrix} c_{112}i_1 & 0 \\ c_{212}i_1 & c_{222}i_1 \end{pmatrix} \right] \left[\begin{pmatrix} c_{111} & c_{211} \\ 0 & c_{221} \end{pmatrix} + \begin{pmatrix} c_{112}i_1 & c_{212}i_1 \\ 0 & c_{222}i_1 \end{pmatrix} \right] + \begin{pmatrix} a_{11} & a_{21} \\ a_{12} & a_{22} \end{pmatrix} \begin{pmatrix} \mathrm{u}_{1,\,t-1} \\ \mathrm{u}_{2,\,t-1} \end{pmatrix} \begin{pmatrix} \mathrm{u}_{1,\,t-1} & \mathrm{u}_{2,\,t-1} \end{pmatrix} \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} + \begin{pmatrix} b_{11} & b_{21} \\ b_{12} & b_{22} \end{pmatrix} \begin{pmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{12,t-1} & h_{22,t-1} \end{pmatrix} \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix} \quad (3)$$

The conditional variance equation for each price can be expressed as follows:

$$\begin{aligned} h_{11,t} = {} & c_{111}^2 + c_{211}^2 + (c_{112}^2 + c_{212}^2) i_1^2 + (2c_{111}c_{112} + 2c_{211}c_{212}) i_1 + a_{11}^2 u_{1,t-1}^2 + 2a_{11}a_{21}u_{1,t-1}u_{2,t-1} + a_{21}^2 u_{2,t-1}^2 + \\ & b_{11}^2 h_{11,t-1} + 2b_{11}b_{21}h_{12,t-1} + b_{21}^2 h_{22,t-1} \end{aligned} \quad (4)$$

$$\begin{aligned} h_{22,t} = {} & c_{221}^2 + c_{222}^2 i_1^2 + 2c_{221}c_{222} i_1 + a_{12}^2 u_{1,t-1}^2 + 2a_{12}a_{22}u_{1,t-1}u_{2,t-1} + a_{22}^2 u_{2,t-1}^2 + \\ & b_{12}^2 h_{11,t-1} + 2b_{12}b_{22}h_{12,t-1} + b_{22}^2 h_{22,t-1} \end{aligned} \quad (5)$$

The conditional mean and covariance models are jointly estimated using standard maximum likelihood procedures. Prior to the estimation of joint models, the time-series properties of price data are evaluated. Specifically, standard unit root tests are applied in order to determine whether price series are stationary or not. To test for the existence of a long-run cointegration relationship and determine the error correction term, the Johansen (1988) test is performed. The threshold parameter is estimated using the grid search technique described above.

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[4]As noted above, Kim and Chavas (2002); Frankel (2006) and Serra and Gil (2012) have stressed the relevance of the influence of interest rates on price volatility. The influence of other regressors such as stocks-to-use ratio was also considered. Results were not statistically significant.

To better understand our data, the Volatility Impulse Response Function (VIRF) approach developed by Hafner and Herwartz (2006) is applied. VIRF provides an effective way to study the impact of external shocks on wheat market volatilities. The VIRF can be defined as follows:

$$V_h(\xi_t) = E\left[vech(H_t)\middle|\xi_t, \psi_{t-1}\right] - E\left[vech(H_t)\middle|\psi_{t-1}\right] \tag{6}$$

where ξ_t is the shock hitting the entire system at time t, ψ_{t-1} represents the observed history up to $t-1$ and $V_h(\xi_t)$ is an N dimensional vector.

4. Empirical application

Price transmission and volatility spillovers along the Slovenian wheat marketing chain are studied by means of a TVECM-MGARCH. Our empirical analysis uses two series of monthly Slovenian producer and consumer wheat prices as well as world stocks-to-use ratio and Slovenian interest rate. Marketing chain prices are obtained from the SI-STAT, Statistical Office of the Republic of Slovenia (SORS, 2012b) and are expressed in euros per kilogram.[5] The world wheat stocks-to-use ratio published by the USDA (2012) is used in this analysis and the information on the short-run interest rate is obtained from the Bank of Slovenia.[6] All series are observed from January 2000 to December 2011, providing a total of 144 observations. Time series used in this study are displayed in Figure 1. Wheat prices have undergone important increases since 2007, which has in turn led to relevant price fluctuations, especially at the producer level. After having registered a declining trend from 2003 to 2007, world wheat stocks-to-use ratio has experienced important increases since the end of 2007. Stocks registered their minimum levels by the end of 2007, coinciding with the world food price crisis.

[5] For the period prior to the introduction of the euro, prices were converted from Slovenian tolars to euros using the irrevocable exchange rate (1 euro = 239.64 Slovenian tolars).

[6] Interest rate was made available to the authors upon request. After the Slovenia adhesion to the Euro zone with the euro adoption on January 1, 2007, the interest rate published by the European Central Bank (ECB, 2013) is used.

The empirical analysis is based on a logarithmic transformation of time series data. Standard Dickey and Fuller (1979) and KPSS (Kwiatkowski *et al.*, 1992) tests confirm the presence of a single unit root in each series. The results from Johansen (1988) cointegration test indicate that producer and consumer prices are linked through the following long-run relationship:[7]

$$P_{Pr} - \underset{(0.178)}{0.720^{**}} P_{Co} + \underset{(0.082)}{1.744^{**}} = v_t \qquad (7)$$

The sup-LR test statistic (see Table 1[8]) allows rejecting linearity against a TVECM that shows different price patterns, depending on the magnitude and sign of the error correction term. Specifically, two price behavior regimes can be found in the Slovenian wheat sector, one (regime $i = 1$) mainly corresponding to negative and very small positive error correction term values (ECT<=0.134), and a second regime ($i = 2$) corresponding to ECT>0.134. Results of the TVECM-MGARCH estimation are presented in Table 2. We first focus on the conditional mean model that studies price-level behaviour. Parameter estimates provide evidence that both producer and consumer prices only adjust to deviations from the long-run equilibrium relationship in the second regime. Positive values of the error correction term characterizing price regime II, are registered when the producer (consumer) price is too expensive (cheap), requiring a decline (increase) to maintain market equilibrium. Note that adjustment towards the equilibrium in the second regime involves increasing retail marketing margins. Conversely, when the ECT is negative, or takes very small positive values, producer and consumer prices do not react to deviations from the long-run equilibrium. Thus, while the price received by agricultural producers does not adjust to increase when it is too cheap, it is instead reduced when it is too expensive. Prices received by retailers tend to increase when the price is cheap and do not react when the wheat price is expensive. This may indicate that retailers use their market power to increase marketing margins. Parameters also indicate that the degree of producer price response is higher than the consumer price adjustment. These results are expected and are in line with previous literature that suggests that upstream prices generally do all the adjustment compared to consumer prices that are sticky and slowly-responsive to market shocks (Goodwin and

[7] Details on unit root and cointegration test results are available from the authors upon request.

[8] The lag order of the TVECM is selected using the Akaike and Schwartz Bayesian criteria.

Holt, 1999; Peltzman, 2000; Serra and Goodwin, 2003; Ben Kaabia and Gil, 2007; Hassouneh et al., 2012).

Stocks-to-use ratio parameters (λ_i) suggest that producer prices decrease as a response to an increase in the international wheat stock levels and this adjustment only occurs in the second regime (where producer prices are too expensive). The negative relationship between stocks and producer prices can be perceived in Figure 1 that shows that producer prices reached their highest levels when the lowest level of world stocks-to-use ratio was observed. Stock building is specially relevant during low price periods, when economic agents prefer to postpone sales into the future. Findings are expected and are compatible with previous literature that has found that when stock levels decline, prices become more sensitive to shocks (Wright, 2011; Balcombe, 2011; Serra and Gil, 2012). In contrast to producer prices, consumer prices do not react to stock changes.

In the following lines, we focus on discussing the conditional variance model results. In order to check for residual autocorrelations, Hosking's multivariate test statistic (Hosking, 1981) is applied. Results suggest that the model is correctly specified. The BEKK-MGARCH parameter estimates cannot be interpreted in a straightforward manner. Inferences can be however drawn from the nonlinear parameter functions in the conditional variance equations presented in Table 3. Results indicate that producer price volatility h_{11t} is positively affected by its own lagged volatility $h_{11,t-1}$ and by past volatility in consumer prices $h_{22,t-1}$. In other words, higher levels of volatility in the past bring higher current instability in producer prices. Parameters also suggest that the influence of interest rate on the conditional producer price volatility is positive and statistically significant. Hence, more expensive credit markets imply higher fluctuations in prices received by agricultural producers. Results are consistent within the Slovenian context where milling enterprises are the major wheat buyers and holders of wheat storage. They largely finance wheat stocks through loans obtained from banks. The increase in interest rates causes higher storage costs, which in turn can lead to reduced stock levels and increased fluctuations in wheat producer prices. Serra and Gil (2012) found a positive relationship between corn price and interest rate volatility. In contrast to producer price instability, consumer price volatility (h_{22t}) is mainly affected by past market shocks in either producer and consumer markets ($u_{2,t-1}^2$, $u_{1,t-1}^2$ and $u_{1,t-1}u_{2,t-1}$ are all statistically significant). Hence, volatility spillovers flow in both directions, from consumer to producer and vice-versa. The mechanisms through which these instabilities are transmitted however differ: while past volatility in the consumer market induces current volatility in producer prices, they are past producer market shocks that cause instability in consumer prices.

According to Hafner and Herwartz (2006), VIRF depends on the history of the series. In this application, a shock occurring September 2007, just before the financial crisis, is examined. VIRFs suggest that producer price volatility increases during the first two weeks after the shock and decreases thereafter, returning after about 8 weeks to pre-shock levels (see Figure 2). External shocks are also seen to affect the consumer price volatility. This volatility tends to disappear after about 8 weeks (see Figure 3). It is important to note that producer price volatility seems to be more affected by price system shocks than consumer price volatility, yielding bigger responses in magnitude. These findings are expected and are consistent with TVECM-MGARCH results that suggest that producer prices are characterized by higher adjustment relative to consumer prices.

5. Concluding remarks

Over the recent years, significant changes in world agricultural commodity prices have been observed. The objective of this paper is to assess price transmission and volatility spillovers among producer and consumer prices for wheat in Slovenia, the most important directly marketed field crop. Wheat plays an important role in Slovenian crop output value. As most wheat production is situated in the less developed Eastern part of Slovenia, it can further contribute to more equitable regional farm and rural development. Wheat is the main ingredient in bread and cereal household consumption, representing around one-fifth of households' expenditures on food. In short, on the supply side, wheat plays a crucial role for agriculture in the less developed part of Slovenia, while, on the demand side, it strongly affects households' food expenditures. In order to achieve our research objective, a TVECM-MGARCH model with exogenous variables is fit to price data. To the best of our knowledge, no previous research has jointly applied both models to study price transmission and volatility spillovers along the food marketing chain.

Two regimes characterize price-level dynamics. While the first one is characterized by high retail margins, the second involves low retail profits. Probably due to the high market power exerted by retailers, prices do not react to deviations from their long-run parity in the first regime. However, both prices are found to adjust in the second regime, where deviations from the long-run parity harm retail margins. Results also suggest a negative correlation between changes in wheat stocks-to-use ratio and wheat producer prices. Results show that volatility spillovers between consumer and producer markets flow in both directions. The mechanisms through which these instabilities are transmitted however differ: while past volatility in the consumer market induces current volatility in producer prices, past producer market shocks cause instability in consumer prices. Further, higher interest rates are found to destabilize producer markets. VIRFs show that external shocks cause higher instability on producer than on consumer prices. The volatility effects of these shocks disappear after about 8 weeks.

Paper results provide some important policy implications. If retail marketing margins increase at the expense of producer margins (the second regime), then the probability that agricultural producers abandon the sector increases. This may lead to a strong restructuring of the sector unless public intervention prevents it. Second, evidence is found that stabilization of price behavior at one level of the marketing chain will bring stability at the other levels. As a result, any policy directed towards guaranteeing stable agricultural producer incomes will also lead to more stable consumer prices. Third, international stock changes appear to be a relevant influence on national food price levels, but not on their fluctuations. In contrast, market price instability seems to be related with macroeconomic conditions, specifically to high interest rates. Macroeconomic policy is thus likely to have an impact on food price volatility.

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Figure 1. Monthly time series data.

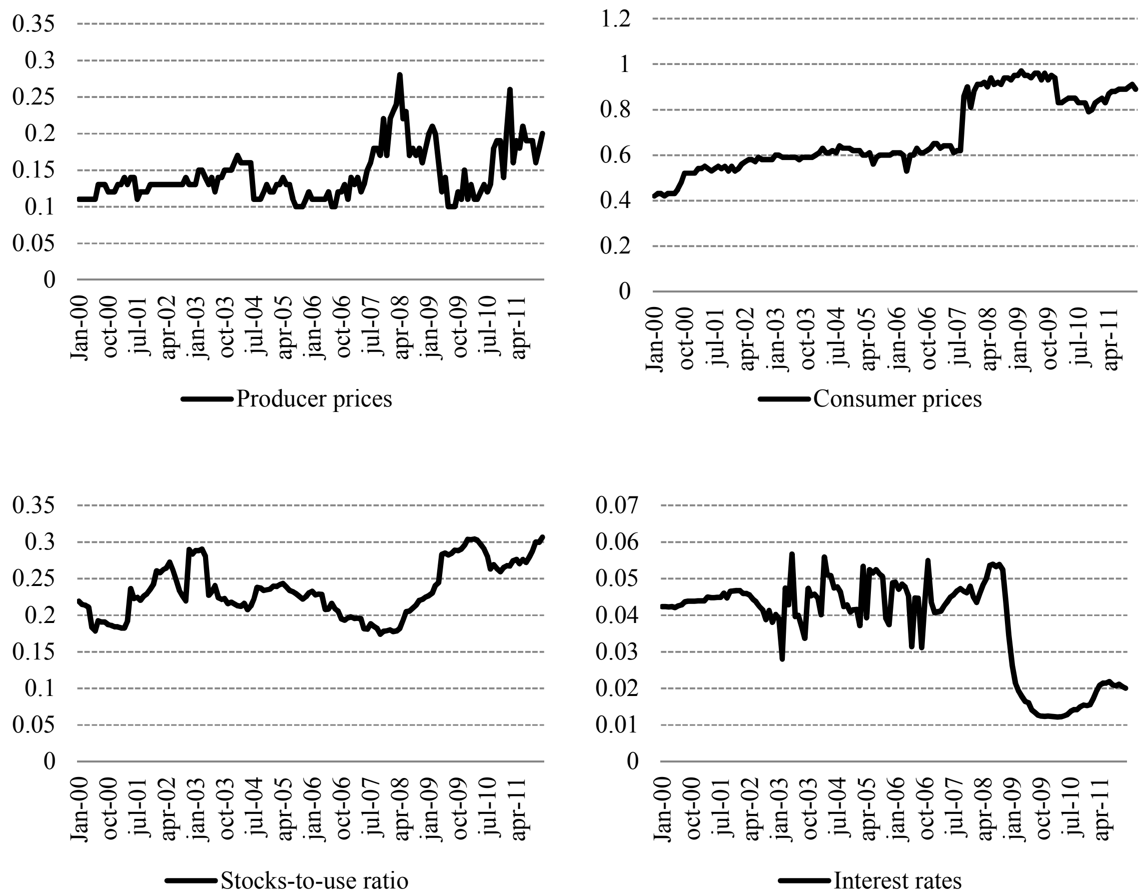

Figure 2. Producer volatility impulse response function

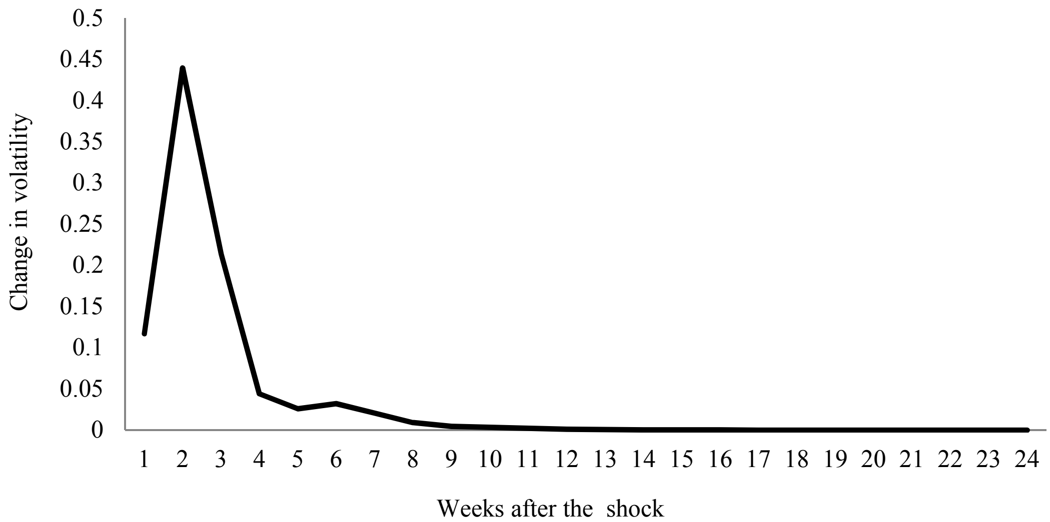

Figure 3. Consumer volatility impulse response function

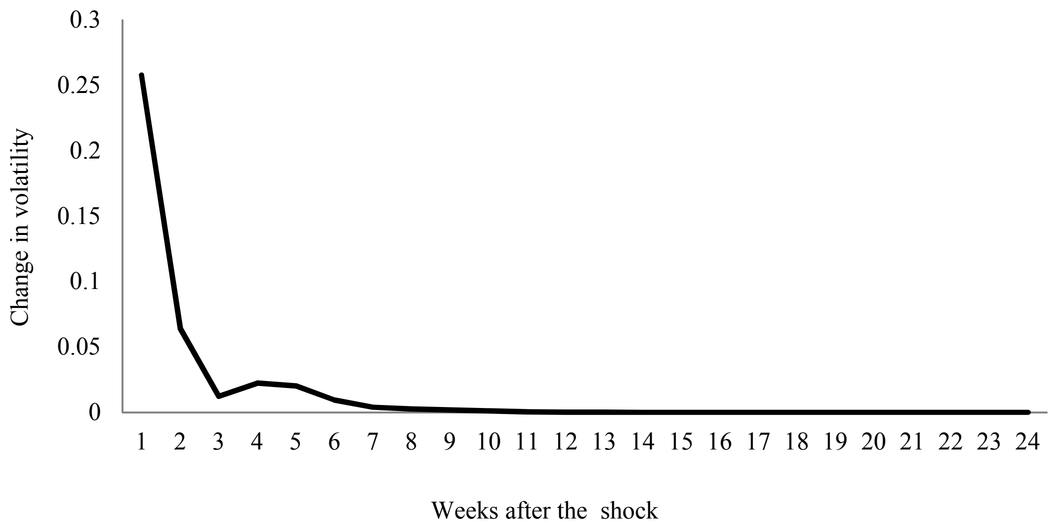

Table 1. TVECM: Thresholds and Sup-LR test.

Threshold (C)	Sup-LR test (p-value)
0.134	19.423 (0.043)

Table 2. Producer - Consumer MGARCH model: mean and variance equations

TVECM parameters:

$$\Delta P_t = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \alpha_{1,P} \\ \alpha_{2,P} \end{pmatrix} v_{t-1} + \begin{pmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{pmatrix} \begin{pmatrix} \Delta p_{\mathrm{Pr},t\text{-}1} \\ \Delta p_{\mathrm{Co},t\text{-}1} \end{pmatrix} + \begin{pmatrix} \lambda_1 \\ \lambda_2 \end{pmatrix} \Delta s_{t-1}$$

	Producer equation		Consumer equation	
	$i=1$	$i=2$	$i=1$	$i=2$
$\alpha_{\mathrm{i,p}}$	-0.064 (0.058)	-0.470** (0.063)	-0.010 (0.021)	0.033* (0.019)
$\alpha_{1,\mathrm{i}}$	-0.353** (0.066)	0.194 (0.304)	-0.071** (0.025)	-0.377** (0.122)
$\alpha_{2,\mathrm{i}}$	0.277** (0.134)	0.168 (0.237)	0.067 (0.041)	-0.314** (0.116)
λ_i	-0.278 (0.244)	-0.403** (0.165)	-0.048 (0.052)	-0.078 (0.055)
α_i	0.042** (0.008)		-0.002 (0.003)	

GARCH model parameters:

$$C = \begin{pmatrix} c_{111} & 0 \\ c_{211} & c_{221} \end{pmatrix} + \begin{pmatrix} c_{112} i_1 & 0 \\ c_{212} i_1 & c_{222} i_1 \end{pmatrix},\ A = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix}, \text{ and } B = \begin{pmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{pmatrix}$$

	$i=1$	$i=2$
c_{1i1}	0.104** (0.009)	
c_{2i1}	-0.008** (0.004)	-0.000 (0.014)
c_{1i2}	0.075 (0.063)	
c_{2i2}	-0.045** (0.021)	-0.000 (0.050)
a_{1i}	0.321** (0.100)	0.294** (0.035)
a_{2i}	-0.611*(0.361)	0.693** (0.166)
b_{1i}	-0.185 (0.224)	-0.094** (0.030)
b_{2i}	-0.612** (0.260)	0. 147** (0.065)
Hosking's Multivariate Q statistic		0.373

*(**) denotes statistical significance at the 10(5) per cent level.

Table 3. Conditional variance equations.

$h_{11t} =$	0.011**	+7.732 e-3 i_1^2	+0.016** i_1	+0.103 $u_{1,t-1}^2$	-0.393 $u_{1,t-1}u_{2,t-1}$	+0.374 $u_{2,t-1}^2$
	+0.034** $h_{11,t-1}$	+0.226 $h_{12,t-1}$	+0.375** $h_{22,t-1}$			
$h_{22t} =$	3.943 e-15	+1.732 e-13 i_1^2	+5.226 e-14 i_1	+0.086** $u_{1,t-1}^2$	+0.407** $u_{1,t-1}u_{2,t-1}$	+0.480** $u_{2,t-1}^2$
	+8.906e-3 $h_{11,t-1}$	-0.028 $h_{12,t-1}$	+0.022 $h_{22,t-1}$			

*(**) denotes statistical significance at the 10(5) per cent level.

h_{11} = producer price variance, h_{22} = consumer price variance, i_1 = interest rate volatility, u_1 = producer market shocks, u_2 = consumer market shocks.