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Original Paper

Mathematical and econometric methods in price transmission analysis

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ABSTRACT

Price transmission analysis has gained a lot of attention in recent years. As the research in this area evolved, authors came with newer and newer methods and models with the aim to properly quantify the price transmission mechanism. Generally prices can be transmitted horizontally, across different locations, or vertically, along the vertical supply chain. In our paper, we focus on horizontal price transmission analysis. The aim of this paper is to bring a brief overview of methods applied in horizontal price transmission. By applying different methods we try to answer the question, which of the methods would be more appropriate to analyze horizontal price transmission in case of Slovak milk market. We apply the time series analysis, particularly the Engle - Granger methodology, Johansen cointegration test and threshold cointegration. Monthly data for producer prices of raw milk are used, covering the period from January 2005 to June 2017. Our results confirm that the asymmetric threshold cointegration model describes our data better than the other two models.

KEYWORDS: cointegration analysis, error correction models

JEL CLASSIFICATION: C13, C32, Q11

INTRODUCTION

The process of transmission of price changes in the agro-food sector, at the vertical or horizontal level, has become a widely studied area in the agricultural economy in the last years.

At the end of the last century attention of researchers has increasingly begun to focus on examining the price relationships within the food supply chain. Along with this, different econometric techniques started to develop. One of the first methods used to study price transmission were simple regression and correlation analysis, followed by dynamic regression models, represented by Vector Autoregression (VAR) model. VAR model formed a basis for estimating the Impulse Response Functions (IRF) as well as cointegration techniques and Vector Error Correction (VEC) model. VEC models were later improved to describe nonlinear and asymmetric patterns in price transmission and threshold cointegration

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models and asymmetric cointegration models were introduced. Meyer and von Cramon-Taubadel [19] and Frey and Manera [11] presented the comprehensive overview of estimating and testing approaches for asymmetric price transmission.

These approaches have mostly focused on the area of agriculture and food processing sector, and one of the first applications of these methods to the agriculture sector was presented by von Cramon-Taubadel [7] who examined how the price changes were transmitted along the pork meat supply chain in Germany. Many recent studies have followed von Cramon-Taubadel's approach and tested the presence of unit roots and cointegration (Zeng and Gould [27]; Acosta and Valdés [2]; Acosta et al. [3]; Bor et al. [5]; Rezitis and Reziti [23]; Rojas et al. [24]; Luoma et al. [17]; Abdulai [1]; Miller and Hayenga [20]). Their main goal is to prove the existence of asymmetries movement of prices with application of more and more advanced statistical methods.

While many studies focused on vertical price transmission along the food supply chain, prices may be transmitted horizontally across different areas (spatial price transmission) or across different commodities (cross commodity price transmission). The first type of horizontal price transmission is based on the assumption of integrated markets and the Law of One Price. The other one, cross commodity price transmission is driven by substitutability or complementarity between different commodities.

The analysis of horizontal transmission [3, 6, 15] is considered as a common tool in market integration analysis [14]. If the locations are integrated, the transmission of price shocks will be perfect and the price of a product should be freely transmitted between trading partners to attain an integrated and efficient market [4]. "Without integration, there is no mechanism by which excess demand changes may be transferred spatially so that no price shocks are shared between non-integrated locations" [18].

According to Goodwin and Piggott [13] or Muratori and Fricke [21] as basic mechanisms of integration are considered the spatial trade, arbitrage and hypothesis related to the Law of One Price (LOP). The arbitrage uses the advantage of a price difference between two or more separated markets. In an equilibrium concept, in a well-functioning market, the price shocks occurring in one market, cause responses in other markets [25].

$$P_j - P_i \leq r_{ij} \qquad (1)$$

where r_{ij} are the costs of moving of products from market i to market j. These costs contain all relevant costs of arranging the transaction between two markets [13]. Also, Goodwin and Harper [12] or Lo and Zivot [16] identify the significant transaction costs in market integration.

In this study, we focus on horizontal price transmission analysis. Our aim is to bring a brief overview of methods applied in horizontal price transmission and by applying different methods we try to answer the question, which of the methods would be more appropriate to analyze horizontal price transmission in case of Slovak milk market. We apply the time series analysis, particularly the Engle - Granger methodology, Johansen cointegration test and threshold cointegration analysis. Monthly data for producer prices of raw milk of Slovakia and the European Union are used, covering the period from January 2005 to June 2017.

MATERIAL AND METHODS

Monthly price data (from 2005 till 2017) are used to test the price movements from European toward Slovak market and vice versa. The individual price series of raw milk are illustrated in Figure 1 and the descriptive statistics of examined variables are in Table 1. We applied the logarithmic transformation of variables to interpret the results in the percentage change.

Before the examining the relationship between variables, the stationarity of selected data series is needed to be tested. A simple first order autoregressive process can be written as:

$$Y_t = \mu_0 + \mu_{1t} + \alpha Y_{t-1} + \varepsilon_t \qquad (2)$$

where Y_t is the stochastic process, μ_0, μ_1, α are parameters, t is the time period, ε_t is a random error term (with white noise properties of zero mean, constant variance and the zero covariance). To test the stationarity of time series we used the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) test [22]. PP test was conducted because the ADF test loses its power for sufficiently large values of k, the number of lags. It includes an automatic correction to the Dickey-Fuller process for autocorrelated residuals. The number of lagged difference terms to include is often determined empirically; the idea is to include enough terms so that the error term in the test is serially uncorrelated. The number of lags of a dependent variable is determined by the Akaike Information Criterion (AIC).

Engle - Granger test of cointegration and error correction model (ECM)

The procedure to test co-integration was developed by Engle and Granger [10]. It involves the estimation static cointegrating regression, using OLS, and applying unit root tests (the ADF and Phillips-Perron to the estimated residuals) in order to test the null hypothesis of no cointegration.

$$y_t = \alpha + \beta x_t + \upsilon_t \qquad (3)$$

if y and x are integrated of the first order I(1) then the residual t from the regression of those series would also be I(1), unless they are cointegrated. Thus if the residuals are distributed I(1) we accept the null hypothesis of no cointegration, but if the residuals are I(0) then we reject the null and accept that y and x are cointegrated.

Error correction model

If the null of absence of cointegration is rejected in the Engle and Granger procedure [10], the adjustment to the long-run equilibrium can be modelled through an error correction model (ECM) specification, such as:

$$\Delta P_{1t} = \alpha + \sum_{j=1}^{k} \beta_j \Delta P_{2t-j+1} + \gamma v_{t-1} + e_t \qquad (4)$$

where P_{1t} and P_{2t} are two related prices, indicator Δ is the difference indicator, β and γ are the estimated coefficients and υ are the deviations from the long run equilibrium [26].

Johansen cointegration test

As a second test of cointegration we employ the Johansen approach to test for cointegration. The Johansen approach is based on a vector autoregressive model and reformulates it into a vector error correction model:

$$Z_t = A_1 Z_{t-1} + \ldots + A_k Z_{t-k} + \varepsilon_t \qquad (5)$$

$$\Delta Z_t = \sum_{i=1}^{k-1} \Gamma_i \Delta Z_{t-i} + \Pi Z_{t-k} + \varepsilon_t \qquad (6)$$

where Z_t is a vector of non-stationary variables, A are different matrices of parameters, t is time subscript, k is the number of lags and ε_t is the error term assumed to follow i.i.d. process with a zero mean and normally distributed $N(0, \sigma 2)$ error structure. The estimates of Γ_i measure the short-run adjustment to changes in the endogenous variables, while Π contains information on the long-run cointegrating relationships between variables in the model.

Threshold cointegration approach

The above cointegration tests assume symmetric price transmission. In order to capture asymmetric movements in the residuals, Enders and Granger [8] and Enders and Siklos [9] propose to use threshold cointegration approach. Assuming the long run relationship between two nonstationary variables X and Y:

$$Y_t = \lambda_0 + \lambda_1 X_t + \mu_t \qquad (7)$$

where μ is the error term. Engle and Granger (1987) show, that cointegration exists if the null hypothesis $\rho = 0$ is rejected in:

$$\Delta\mu_t = \rho\mu_{t-1} + \xi_t \qquad (8)$$

where ξ is the error term for the residuals. Adjustment of the series of residuals expressed in $\rho\mu_{t-1}$ would be symmetric. To capture the assymmetry in adjustment process, a two-regime threshold cointegration approach should be used:

$$\Delta\mu_t = I_t \rho_1 \mu_{t-1} + (1 - I_t)\rho_2 \mu_{t-1} + \xi_t \qquad (9)$$

where I_t is the Heaviside indicator $I_t = 1$ *if* $\mu_{t-1} \geq \tau$ or $I_t = 0$ *if* $\mu_{t-1} < \tau$. If μ_{t-1} is bigger than the threshold τ, then adjustment is at the rate ρ_1. If μ_{t-1} is smaller than the threshold τ, adjustment is shown in ρ_2. If $\rho_1 = \rho_2$, then the adjustment process is symmetric.

If the null hypothesis $\rho_1 = \rho_2 = 0$ is rejected, then X and Y are cointegrated and the following TAR model is estimated:

$$\Delta Y_t = \theta_Y + \delta_Y^+ E_{t-1}^+ + \delta_Y^- E_{t-1}^- + \sum_{j=1}^{J} \alpha_{Yj}^+ \Delta Y_{t-j}^+ + \sum_{j=1}^{J} \alpha_{Yj}^- \Delta Y_{t-j}^- + \sum_{j=1}^{J} \beta_{Yj}^+ \Delta X_{t-j}^+ + \sum_{j=1}^{J} \beta_{Yj}^- \Delta X_{t-j}^- + \upsilon_{Yt} \qquad (10)$$

where ΔY_t and ΔX_t are dependent and independent variables in their first differences, E is the error correction term, δ represents the speed of adjustment coefficients of ΔY_t if Y_{t-1} is above and below its long-run equilibrium, θ, δ, α and β are coefficients and υ is the error term, t is time subscript and j is the number of lags.

Two error correction terms are defined as:

$$E_{t-1}^{+} = I_t \mu_{t-1} \tag{11}$$

$$E_{t-1}^{-} = (1 - I_t)\mu_{t-1} \tag{12}$$

Enders and Granger [8] and Enders and Siklos [9] proposed also a model for cointegration, known as a momentum threshold autoregressive model. The term “momentum” describes the rate of acceleration of prices and takes into account steep variations in the residuals; it is especially valuable when the adjustment is believed to exhibit more momentum in one direction than the other. Heaviside Indicator in this case is $I_t = 1$ *if* $\Delta\mu_{t-1} \geq \tau$ or $I_t = 0$ *if* $\Delta\mu_{t-1} < \tau$. To summarize, four asymmetric models are considered in our study. They are threshold autoregression model with threshold value equal to zero; threshold autoregression model with threshold value estimated (consistent threshold autoregression model); momentum threshold autoregression model with threshold value equal to zero; and consistent momentum threshold autoregression model with threshold value estimated. A model with the lowest AIC and BIC (Bayesian information criterion) will be used.

RESULTS AND DISCUSSION

The development of raw milk prices in Slovakia follows similar trend and patterns as the EU prices, suggesting there may be a long-term relationship present among the prices (Figure 1). The most significant increases in prices are recorded over the period 2007 - 2008 and in the year 2014. In 2008 - 2009 milk prices have fallen from their historical maximum by approximately 40 - 50%. This development was caused by the reduction in demand for dairy products due to economic recession and surplus of supply in international markets. As a result, stocks of some milk products as butter and milk powder increased, particularly in the US and EU countries. This situation had very damaging effects on the dairy sector, with some countries starting to rethink their long-term strategies. These strategies and also mitigation of economic crises caused the milk prices to increase and climb up to their maximum in 2013. High milk prices in 2013 reflected in lower demand and increased milk production in China together with the embargo of the Russian Federation led to the decrease in milk prices again.

As seen from the Figure 1, the development of price series suggests there may exist a long run relationship between the EU and Slovak price series. Therefore we examined the extent to which increases in the international price of raw milk in the European Union have been transmitted to domestic Slovak prices.

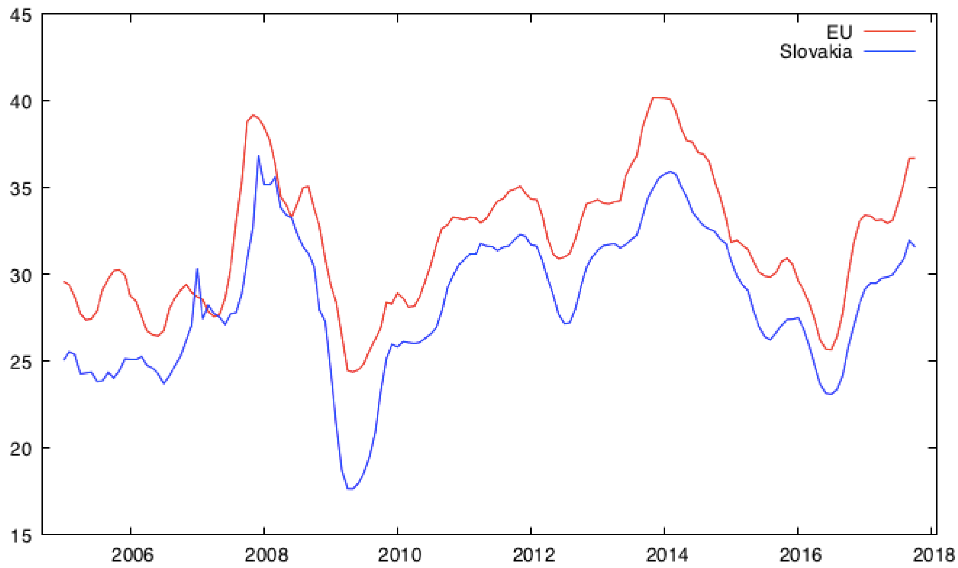

Figure 1 Historical Price Series of Cow's Raw Milk in EURO/100 kg
Source: Milk Market Observatory, European Commission

Table 1 Descriptive statistics

	Observations	Mean	Median	S.D.	Min.	Max.
Slovakia	154	28.50	28.27	4.062	17.67	36.88
European Union	154	31.87	31.86	3.85	24.39	40.21

Source: own calculations

Before examining the cointegration relationship between the variables, it was essential to test them for unit root and identify the order of stationarity. To check the stationarity we used the augmented Dickey-Fuller and Phillips-Perron tests (Table 2). Each variable was found to be non-stationary and also integrated of the first order, I(1). In the other words, the variables follow a random walk, but the first difference is stationary, I(0).

Table 2 Dickey-Fuller and Philips-Perron tests

Variables	**ADF test**		**PP test**	
	level form	**1st diff.**	**level form**	**1st diff**
European Union	0.37	0.00***	0.29	0.00***
	(-2.42)	(-6.69)	(-2.57)	(-5.16)
Slovakia	0.16	0.01***	0.26	0.00***
	(-2.92)	(-4.05)	(-2.65)	(-6.90)

Source: own calculations. Note: *, **, *** refers to the significance at 10%, 5%, 1% level

Engle - Granger cointegration test consists of testing the stationary of residuals form cointegration regression. The results (in Table 3) indicate that there is a cointegration relationship present between the producer prices of cow’s milk in Slovakia and the European Union in the long-run. In the next step, the error correction model was set up (Table 3). It allows estimating parameters, determining the speed of adjustment to deviations from the long-term equilibrium (error correction term). Error correction term indicates the rate of adaptation (speed) of domestic prices to potential price shocks. The value needs to be negative (to ensure the variable leads to restore back to equilibrium) and significant. Since the data in the analysis are used in the logarithm form, the coefficient of error correction model also indicates the approximate impact of price change of this commodity in EU to Slovak (the short elasticity of price transmission).

Table 3 Engle – Granger cointegration test and error correction model

	Coefficient	T-Stat	p-value
Cointegration test	1.139	-4.301	0.000
Error correction model (EU → SK)			
Error correction term	-0.144	-3.796	0.000
Long Run Elasticities	0.737	9.092	0.000

Source: own calculations. Note: Crit. Values: -4.3266***, -3.7809**, -3.4959*
(*, **, *** refers to the significance at 10%, 5%, 1% level)

Table 4 Johansen cointegration test and vector error correction model

Cointegration test	Trace Stat	Max Stat
Maximum rank 0	20.289	19.883
Maximum rank 1	0.405***	0.405***
VEC Model (EU → SK)		
Error correction term	-0.086**	
Long Run Elasticities	1.302***	

Source: own calculations. Note: *, **, *** refers to the significance at 10%, 5%, 1% level

Similar results of cointegration were obtained by Johansen cointegration test. The test results indicated the presence of cointegrating relationship between the variables, the error correction term in the VEC model is negative and statistically significant. As the last step, we set up a threshold cointegration model that allows asymmetric price transmission (APT) of Slovak prices to price shocks in the EU.

Table 5 Consistent momentum threshold autoregression model (cMTAR)

Model	Threshold	Lags	H_0: no cointegration	H_0: no APT
cMTAR	0.017	3	19.399*** [0.000]	7.408*** [0.007]
	Positive		Negative	
Error correction term	-0.376***		-0.096*	
Long run elasticities	0.426***		0.191***	

Source: own calculations. Note: *, **, *** refers to the significance at 10%, 5%, 1% level

The theory does not guide us in the exact model specification and therefore in this paper, we used four different threshold models: threshold autoregression model, consistent threshold autoregression model, momentum threshold autoregression model, and consistent momentum threshold autoregression model. We report the results for consistent momentum threshold autoregression model with the lowest AIC and BIC. Estimated models show, that the prices are cointegrated with threshold adjustment.

From the results (Table 5) it follows that there is a strong evidence of asymmetry for Slovak and the EU price of milk. In other words, Slovak prices react differently to rise and decline in the EU prices. The results also indicate that the asymmetric threshold cointegration model describes our data better than the other two models.

CONCLUSIONS

This study analyses the relationship between raw cow's milk markets in Slovakia and in the European Union. We aim to bring a brief overview of methods applied in horizontal price transmission and to assess the linkage and patterns between the prices of raw cow's milk. To clarify the relationships between the prices in the markets we apply different methods starting with the unit root tests, Engle – Granger cointegration test, Johansen cointegration test and the test for asymmetric price transmission and we set up appropriate error correction models. We applied monthly data covering the period from January 2005 to June 2017. All applied cointegration tests confirmed the price pairs are cointegrated and there exists a long-run relationship between variables. Our results also indicate that the prices are cointegrated with threshold adjustment and there is a strong evidence of asymmetry for Slovak and the EU price of milk. This brings us to the conclusion that the asymmetric threshold cointegration model describes our data better than the other two models.

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