Asymmetric Retail Gasoline and Diesel Price Reactions in Slovak Market[1]

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Abstract

In the paper we respond a question, if Slovak retail gasoline and diesel prices respond more quickly when crude oil price rises rather than when it decreases. A theoretical explanation of asymmetric retail gasoline and diesel price reactions is addressed by examining the theory of strategic interactions between firm and its consumers. By investigating the traditional approach based on error correction models and vector error correction models, we reject the asymmetric gasoline and diesel price reaction hypotheses in the Slovak market. Considering the theory of strategic interactions between a firm and its consumers, a firm is minimising its adjustment cost function in a linear exponential form. Solving the problem of firm, we derive an econometric specification of a gasoline and diesel price reaction function. Estimating the specification we do not reject asymmetric gasoline and diesel price reaction hypotheses in Slovak market.

Keywords: *asymmetric retail gasoline and diesel price reactions, error correction models, linex adjustment cost function*

JEL Classification: C12, C26, Q41

Introduction

Numerous studies have dealt with the transmission of crude oil prices to retail gasoline prices and indicate that retail gasoline prices respond more quickly when crude oil prices rise than when they decrease; e.g. Radchenko (2005), Grasso and Manera (2007), Honarvar (2009), Meyler (2009), Liu, Margaritis and

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Tourani-Rad (2010), Rahman (2016), Sun et al. (2018). Bacon (1991) named this asymmetric retail gasoline price adjustment as “rockets and feathers” effect. His study was followed by a paper from Borenstein, Cameron and Gilbert (1997) who provided strong evidence of an asymmetry in the US market between 1986 and 1992 in different stages of the production and distribution of gasoline.

Douglas and Herrera (2010) provide an explanation of the “rockets and feathers” effect. According to the authors, asymmetric retail gasoline price reactions to crude oil price changes can be addressed by the theory of strategic interactions between a firm and its consumers; e.g. Okun (1981). As Rotemberg (2011) highlights, “The basic idea is that some consumers become angry and punish firms that demonstrate that they lack a minimal level of altruism. The fear of angering a minority of customers can be sufficient for selfish firms to act altruistically as well.” The altruistic behaviour by firms can explain “that, even when prices do change, prices seem to be more responsive to changes in factor cost than to changes in demand that have the same effect on marginal cost” (Rotemberg, 2011).

Consumers consider it unfair for a firm to raise the price of an item whose demand has suddenly increased. By contrast, they generally regard it as fair if a firm increases its prices when the price of its inputs rises. Consumers consider a firm to be altruistic if it increases its prices when the price of its inputs rises. However, consumers experience regret (or disappointment) if a firm increases the price of an item whose demand has increased. “An altruistic firm would be expected to internalize this regret cost to some extent, and thereby keep its price constant, even in situations where a selfish firm would raise its own price” (Rotemberg, 2011).

The theory of strategic interactions between a firm and its consumers is one of three theories explaining the price stickiness hypothesis which is used in New Keynesian monetary models. Douglas and Herrera (2010) argue that a good testing ground for various theories of price stickiness is the dataset describing price adjustment of gasoline sellers.

Particularly, the theory predicting price adjustment asymmetry in the retail gasoline market is the theory of strategic interactions between a firm and its consumers. Assume that a firm behaves altruistically in the sense that it does not increase its price if demand increases, but, on the other hand, it increases price if the crude oil price increases. Then we predict that after the crude oil price rises, an altruistic firm will raise retail gasoline price to a more moderate extent than a selfish firm would. It is because an altruistic firm, through fear of angering a minority of customers, will not react directly when demand changes, while a selfish firm can react freely. One way for an altruistic firm to adjust prices in response to an increase in demand is to raise the gasoline price sharply after crude oil price rises and, conversely, to lower the gasoline price slightly after crude oil price decreases.

Borenstein, Cameron and Gilbert (1997) suggest three possible explanations for the asymmetric response of gasoline prices: the oligopolistic coordination theory, the production and inventory cost of adjustment, and the search theory.

The commonly used approaches in empirical studies of retail fuel price asymmetries involve error correction models (ECM) and vector error correction models (VEC); e.g. Radchenko (2005), Grasso and Manera (2007), Honarvar (2009), Liu, Margaritis, and Tourani-Rad (2010). Such an approach is also used in our paper, investigating the reactions of retail gasoline prices to changes in crude oil prices. Using this approach, we reject the "rockets and feathers" effect with regard to the Slovak gasoline and diesel market.

For our part, we provide an alternative empirical approach based on the linear exponential (linex) adjustment costs formulation. Using a similar approach, Pfann and Palm (1993) provided an example of an asymmetry approach in the labour market. According to this approach, the firing costs of manufacturing exceed the hiring costs. As Adda and Cooper (2003) state, Pfann and Palm (1993) estimated the coefficients of the cost function in the linex specification using the generalised method of moments (GMM) approach on data for manufacturing in the Netherlands (quarterly, seasonally unadjusted data for the period 1971-1984) and annual data for U.K. manufacturing. They used data on both production and non-production workers and the employment choices are interdependent from the production function. For both countries, they found evidence of asymmetry. They reported that the costs of firing production workers were lower than the hiring costs. But, the opposite is true for non-production workers. Our ideas are inspired by empirical studies which analysed the U.S. and EMU monetary policy asymmetries provided by Surico (2007a), Surico (2007b) and Surico (2008). He examined the question as to whether central bankers weighed positive and negative deviations of the inflation, output and interest rate from their reference values differently.

According to Okun's (1981) theory of strategic interactions between a firm and its consumers, the adjustment costs of the gasoline and diesel seller will be lower after the crude oil price rises and they will be higher after the crude oil price decreases. The character of this behaviour is similar to the character of the firm's behaviour on the labour market described by Pfann and Palm (1993). Such a price-making process is discretionary.

Cukierman (2002) and Ruge-Murcia (2003), supposed that an asymmetry of monetary policy for output is a source of monetary policy time inconsistency. According to the time inconsistency of the monetary policy theory established by

Kydland and Prescott (1977) and Calvo (1978), monetary authorities' adjustment costs of different economic shocks vary under discretionary and non-discretionary environments. If monetary policy is discretionary, adjustment costs after positive economic shocks are lower than after negative positive shocks. Discretionary monetary policy systematically produces an inflation bias.

Considering the other three theoretical approaches (the oligopolistic coordination theory, the production and inventory cost of adjustment, and the search theory), one can also form the price-making problem as a discretionary process with non-linear adjustment costs.

In this paper we derive an econometric specification of a gasoline and diesel price reaction function. Estimating the specification, we do not reject the "rockets and feathers" effect in Slovak gasoline and diesel market. We analyse the retail gasoline and diesel prices published by the Statistical Office of the Slovak Republic. It is worth noting that a price-making asymmetry can occur on two levels of the selling process. The gasoline and diesel producer sells its product to retail sellers who sell it on to the final consumer. The Slovak producer has dominant market power and the majority of retail sellers buy gasoline and diesel from him. As the corresponding prices on the first level are not published, this prevents our study from determining on which level the price-making asymmetry occurs.

1. Models and Methodology

Two approaches of the "rockets and feathers" effect are applied in our study. The first, the co-integration approach, is based on error correction models (ECM) and vector error correction models (VEC). In the second approach, the price reaction specification is derived from the linex adjustment cost function.

1.1. Co-integration Approach

We are interested in the question as to whether a positive unit change in the oil price has an identical influence on the fuel price as a negative unit change. The error correction model with irreversible behaviour of explanatory variables is considered to be the basic tool for the analysis of the asymmetric price reaction of fuel. The reason for this is clear: if non-stationary price variables are used as the first differences in this model, it is thus easy to separate positive and negative values in the explanatory variable.

A non-stationarity of variables is tested by unit root tests. We prefer the augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1981). In cases where a significant autocorrelation is confirmed by a large number of lagged terms in the Dickey-Fuller test equation, we also adopted the Phillips-Perron (PP) unit root test (Phillips and Perron, 1988).

The single-equation error correction model is essentially an auto-regressive distributed lag model with rearranged terms. We can show this by the auto-regressive distributed lag model of order one with three variables:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \gamma_0 x_t + \gamma_1 x_{t-1} + \delta_0 z_t + \delta_1 z_{t-1} + u_t \quad (1)$$

where y_t is regressand and the average weekly price of gasoline or diesel in time t; x_t is the key regressor – average weekly price of oil in time t; z_t is another relevant regressor in time t; u_t is a stochastic term in time t and β_0, β_1, γ_0, γ_1, δ_0 and δ_1 are unknown parameters of this regression model.

We can rewrite model (1) as the error correction (ECM) model (Engle and Granger, 1987):

$$\Delta y_t = \beta_0 + \gamma_0 \Delta x_t + \delta_0 \Delta z_t + (\beta_1 - 1)\left[y_{t-1} - \frac{(\gamma_0 + \gamma_1)}{1-\beta_1} x_{t-1} - \frac{(\delta_0 + \delta_1)}{1-\beta_1} z_{t-1} \right] + u_t \quad (2)$$

which contains the original (one period lagged) variables in the levels and their first differences. This allows us to explore both the long-run equilibrium relationship (the term in square brackets) and its adjustment along with the short-run dynamics. If a positive unit change of the regressor has an identical influence on the regressand as a negative unit change, we do not have to distinguish between them and we can estimate the overall response with one parameter for one regressor, as in the reversible model (2). But this is precisely a restriction. If this restriction is not valid, the estimation results can be improved by specifying increases ($\Delta^+ x_t$) and decreases ($\Delta^- x_t$) of the explanatory variable as separate variables and also by separating the positive and negative deviations from the long-run equilibrium relationship.

The asymmetric form of this irreversible error correction (A - ECM) model (Granger and Lee, 1989) is:

$$\Delta y_t = \beta_0 + \gamma_0^+ \Delta^+ x_t + \gamma_0^- \Delta^- x_t + \delta_0 \Delta z_t + \lambda^+ e_{t-1} \times D(e_{t-1} > 0) + \lambda^- e_{t-1} \times D(e_{t-1} \le 0) + u_t \quad (3)$$

where $e_{t-1} = y_{t-1} - \frac{(\gamma_0 + \gamma_1)}{1-\beta_1} x_{t-1} - \frac{(\delta_0 + \delta_1)}{1-\beta_1} z_{t-1}$ is one period lagged deviation from the long-run equilibrium relationship; $D(e_{t-1} > 0)$ is a dummy variable that equals 1 if $e_{t-1} > 0$ and equals 0 otherwise; $D(e_{t-1} \le 0)$ is a dummy variable that equals 1 if $e_{t-1} \le 0$ and equals 0 otherwise; λ^+ and λ^- are the corresponding adjustment parameters, β_0, γ_0^+, γ_0^- and δ_0 are also parameters of this regression model.

Model (2) is obtained from model (3) using restrictions $\lambda^+ = \lambda^-$ and $\gamma_0^+ = \gamma_0^-$. This linear hypothesis in the linear model can be tested by the F test. In cases where model (1) has a more extensive dynamic structure, models (2) and (3) will also be more extensive and the test hypothesis will additionally include parameter comparisons for further lags.

Models (2) and (3) are some of the simplest types of error correction models because their long-run equilibrium relationship does not contain any deterministic terms. When searching for the most appropriate specification of the model, it is necessary to analyse different versions of deterministic components as a constant and trend in both the long-term equilibrium relationship as well as in the short-run dynamic part of the equation. This brings us to the well-known five cases of the deterministic part of the model: no constant and no trend, restricted constant and no trend, unrestricted constant and no trend, unrestricted constant and restricted trend, unrestricted constant and unrestricted trend – among these we have to decide.

The single equation error correction models are usually estimated by mean of a two-step Engle-Granger procedure (Engle and Granger, 1987) and the co-integration of variables is confirmed by an ADF test of residuals from the first step. The estimates from the long-run equation (the first step of the Engle-Granger procedure), although consistent, can be substantially biased in small samples. In the first step of the Engle-Granger procedure we use the fully modified ordinary least squares (FMOLS) method proposed by Phillips and Hansen (1990). The FMOLS estimator employs a semi-parametric correction to eliminate problems caused by the long run correlation between the co-integrating equation and stochastic regressors' innovations. The FMOLS estimator is asymptotically unbiased and efficient.

The co-integration of variables can be also verified by bounds testing. Pesaran, Shin and Smith (2001) propose a test for co-integration that is robust with regard to the fact as to whether variables of interest are stationary or integrated of order one, or mutually co-integrated. They suggest a bounds test for co-integration as a test on parameter significance in the co-integrating relationship of the conditional error correction model. After the validation of co-integration, we form the asymmetric ECM and test the appropriate restrictions. In the asymmetric ECM, we do not re-estimate the co-integration relationship which is included in the variable representing the deviation from equilibrium.

We expect that there are co-integrating relationships between the crude oil price and one each for the retail fuel prices for gasoline and for diesel, either individually or jointly; therefore, we are looking for a long-term equilibrium relationship between the price of oil and the retail price of fuel with the help of the vector error correction model (VECM).

Similarly, as the single-equation error correction model is an auto-regressive model, so the vector error correction model is a vector auto-regressive model. We can show it by the vector auto-regressive model of order two:

$$\mathbf{y_t} = \mathbf{\Phi D_t} + \mathbf{\Pi}_1 \mathbf{y_{t\text{-}1}} + \mathbf{\Pi}_2 \mathbf{y_{t\text{-}2}} + \mathbf{u_t} \tag{4}$$

where $\mathbf{y_t}$ is the vector of variables in time t; $\mathbf{D_t}$ is the matrix of deterministic terms (constant, trend, …) in time t; $\mathbf{u_t}$ is the vector of stochastic terms in time t and $\mathbf{\Phi}$, $\mathbf{\Pi_1}$ and $\mathbf{\Pi_2}$ are the matrices of unknown parameters of this model.

We can rewrite model (4) as the vector error correction (VECM) model of order one:

$$\Delta\mathbf{y_t} = \mathbf{\Phi D_t} + \boldsymbol{\alpha\beta}^T \mathbf{y_{t\text{-}1}} + \mathbf{\Phi}_1 \Delta\mathbf{y_{t\text{-}1}} + \mathbf{u_t} \tag{5}$$

where $\boldsymbol{\alpha\beta}^T = (\mathbf{\Pi}_1 + \mathbf{\Pi}_2 - \mathbf{I})$ and $\mathbf{\Phi}_1 = -\mathbf{\Pi}_2$. Model (5) contains the original (one period lagged) variables in the levels and their first differences, and allows us to explore both the long-run equilibrium relationship and its adjustment along with short-run dynamics. Matrix $\boldsymbol{\beta}$ is called a co-integration matrix with co-integration vectors as columns and matrix α is called a loading matrix. Again, it is necessary to analyse different versions of deterministic components $\mathbf{\Phi D_t}$ – the five cases mentioned above.

The asymmetric form of this irreversible vector error correction (A-VECM) model is:

$$\begin{aligned}\Delta\mathbf{y_t} &= \mathbf{\Phi D_t} + \boldsymbol{\alpha}^+\left[\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}} \times D\left(\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}} > \mathbf{0}\right)\right] + \boldsymbol{\alpha}^-\left[\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}} \times D\left(\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}} \le \mathbf{0}\right)\right] + \\ &+ \mathbf{\Phi}_1^+ \Delta^+\mathbf{y_{t\text{-}1}} + \mathbf{\Phi}_1^- \Delta^-\mathbf{y_{t\text{-}1}} + \mathbf{u_t}\end{aligned} \tag{6}$$

where $\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}}$ is the vector of one period lagged deviations from the long-run equilibrium relationships; $D(\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}} > \mathbf{0})$ is the vector of a dummy variable; its element equals 1 if corresponding element of $\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}}$ is positive and equals 0 otherwise; $D(\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}} \le \mathbf{0})$ is the vector of a dummy variable; its element equals 1 if corresponding element of $\boldsymbol{\beta}^T\mathbf{y_{t\text{-}1}}$ is not positive and equals 0 otherwise; α^+ and α^- are the loading matrices of corresponding adjustment parameters and $\mathbf{\Phi_1}^+$ and $\mathbf{\Phi_1}^-$ are also matrices with some pairs of the asymmetric parameters of this model. The multiplication operation in square brackets of model (6) does not represent a matrix product, but the product of elements in the same positions in corresponding vectors. Model (5) is obtained from model (6) using restrictions $\mathbf{\Phi_1}^+ = \mathbf{\Phi_1}^-$ and $\boldsymbol{\alpha}^+ = \boldsymbol{\alpha}^-$.

The test of co-integration in VECM is realized by Johansen's procedure (Johansen, 1988) by the lambda trace statistics depending on the specification of the deterministic components of model (5). After the validation of co-integration, we form the asymmetric VECM and test the appropriate restrictions. In the asymmetric VECM, we do not re-estimate co-integration relationships, which are included in the variables representing deviations from the equilibrium.

1.2. Linex Approach

Consider that gasoline and diesel sellers react asymmetrically to changes in the crude oil price. According to Okun's (1981) theory of strategic interactions between the firm and its consumers, his adjustment costs will be lower after the crude oil price rises and they will be higher after the crude oil price decreases. Therefore, after the fashion of Surico (2007a), Surico (2007b) and Surico (2008) we consider the adjustment costs function F to be in the linex form:

$$F\left[p_t, E_{t-1}(c_t)\right] = \frac{-\gamma\left[p_t - kE_{t-1}(c_t)\right] + e^{\gamma\left[p_t - kE_{t-1}(c_t)\right]} - 1}{\gamma^2} \tag{7}$$

where p_t is the retail gasoline or diesel price, c_t is the crude oil price, k is the technology coefficient and γ is an asymmetry coefficient. A negative value of the coefficient γ implies that a negative value of the difference $p_t - kE_{t-1}(c_t)$ causes higher costs to the price-maker than it would if γ were positive. The linex specification nests the quadratic form as a special case, so that applying l'Hôpital's rule twice when γ tends to zero results in a reduction in the loss function (7) to the following symmetric parameterization:

$$\lim_{\gamma \to 0}\left\{F\left[p_t, E_{t-1}(c_t)\right]\right\} = \frac{1}{2}\left[p_t - kE_{t-1}(c_t)\right]^2$$

The fuel price-maker chooses p_t in order to minimize the cost function (7). The first-order condition with respect to p_t is in the form:

$$\frac{-1 + e^{\gamma\left[p_t - kE_{t-1}(c_t)\right]}}{\gamma} = 0 \tag{8}$$

Condition (8) is a general description of the reaction function of the fuel price-maker. Applying l'Hôpital's rule, whenever coefficient γ tends to zero, the reaction function (8) transforms to the linear form:

$$\lim_{\gamma \to 0}(p_t) = kE_{t-1}(c_t)$$

Performing the second-order Taylor expansion of the exponential terms in (8), we gain:

$$p_t - kE_{t-1}(c_t) + \frac{\gamma}{2}\left[p_t - kE_{t-1}(c_t)\right]^2 + v_t = 0 \tag{9}$$

The remainder of the approximation is v_t and it contains terms of the third or higher orders of the expansion.

We solve equation (9) for p_t and, prior to generalised method of moments estimation (GMM) of the short-run relation, we replace expected values with actual values and we take the first differences of the relation. In practise, we estimate the following nonlinear specification with coefficient restrictions:

$$\Delta p_t = k\Delta c_t - \frac{1}{2}\gamma\Delta\left[\left(p_t - kc_t\right)^2\right] + u_t \tag{10}$$

Modifying the restricted nonlinear specification, we gain a linear unrestricted one in the form:

$$\Delta p_t = \beta_0 + \beta_1\Delta c_t + \beta_2\Delta\left(p_t^2\right) + \beta_3\Delta\left(p_t c_t\right) + \beta_4\Delta\left(c_t^2\right) + u_t \tag{11}$$

The linear specification (11) corresponds to nonlinear (10) if the following coefficient restrictions hold:

$$\beta_0 = 0,\ \beta_3 = -2\beta_1\beta_2 \ \text{ and } \ \beta_1^2\beta_2 = \beta_4 \tag{12}$$

The advantage of the linear form (11) is that well known linear instrument tests – such as the Hausman test of the endogeneity of regressors (Hausman, 1978), the Cragg-Donald *F* test and the Stock-Yogo bias critical values of instrument weakness (Cragg and Donald, 1993 and Stock and Yogo, 2005) – can be applied.

From (8), we can also express the average gasoline or diesel price bias caused by the "rockets and feathers" effect, $\gamma < 0$. The changes in the crude oil prices Δc_t are normally distributed process with zero mean and variance σ^2. Taking the first differences, expected values and logarithms of (8) and after rearranging terms, we gain the price bias in the form:

$$E\left(\Delta p_t\right) = -\frac{k^2\gamma}{2}\sigma^2 \tag{13}$$

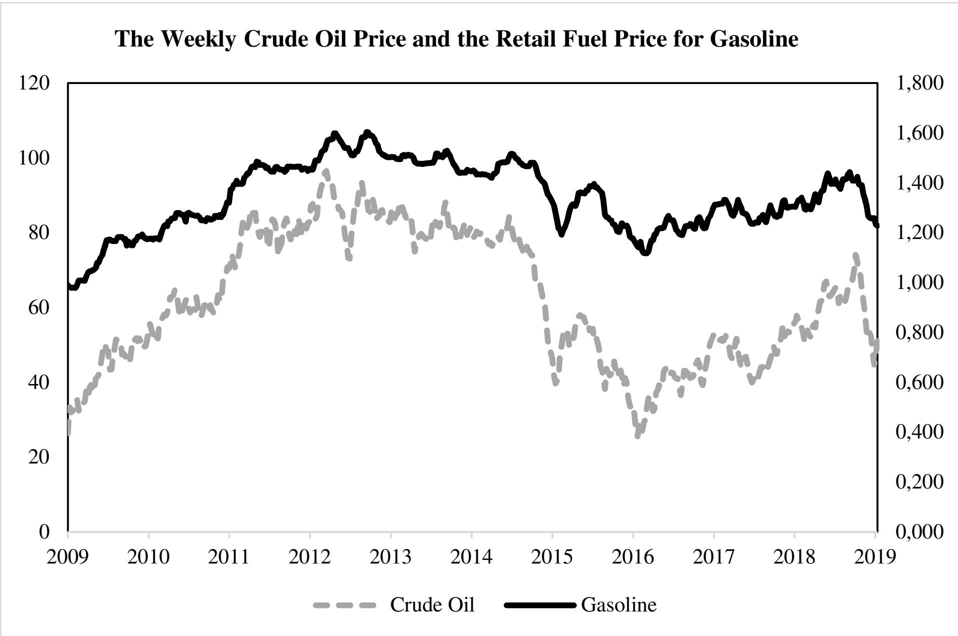
The orthogonality conditions implied by the rational expectation hypothesis makes the GMM a natural candidate to estimate equation (10). To ensure the robustness of our results, we also use the ordinary least square method (OLS) and the two-stage least square method (2SLS) as well as the forward-looking generalised method of moments (GMM1) where crude oil prices are one period leading time series. All the estimates employ both retail 95-octane gasoline prices and diesel prices. If the residuals of the gasoline and diesel equations are statistically significantly correlated, we will also estimate the equation (10) with the system GMM method. The standard errors are computed with the procedure of Newey and West. The most important feature of the procedures explained by Newey and West (1987) is their consistency in the presence of both heteroskedasticity and the autocorrelation of unknown forms. The instrument sets vary for different estimates. The choice of instrument sets is verified by several tests that are mentioned in more details in the results.

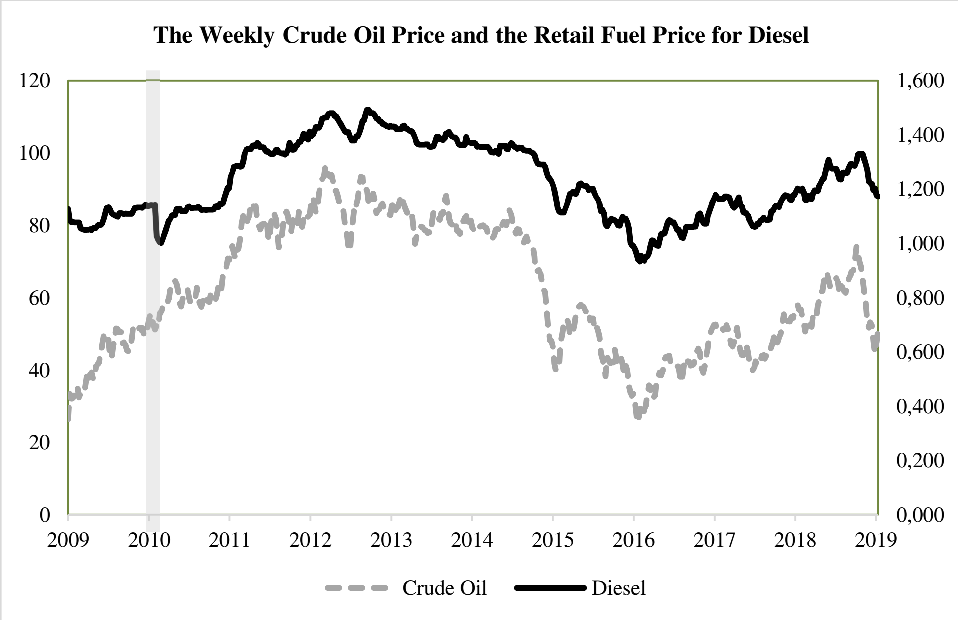
2. Data and Tax Legislation

Data of retail gasoline and diesel prices on Slovak market were gathered from the Statistical Office of the Slovak Republic. The spot prices for crude oil and petroleum products were gathered from the U.S. Energy Information Administration – the agency responsible for collecting, analysing, and disseminating energy information. Since we only had the weekly retail gasoline and diesel prices data, we could only use the weekly Europe Brent Spot Price FOB Dollars per Barrel for our analysis.

The weekly retail gasoline and diesel prices data are in euros, so we need to recalculate the crude oil prices from dollars to euros. We converted the daily oil prices in dollars by the euro exchange rate in dollars and then aggregated them into weekly averages. The daily reference exchange rate data series are gathered from the European Central Bank. All data pertains to the period from the first week of 2009 till the second week of 2019, so we have 524 observations available.

Figure 1
The Weekly Crude Oil Price and the Retail Fuel Price for Gasoline and for Diesel





Source: Authors' illustration.

Liu, Margaritis, and Tourani-Rad (2010) outline that taxes and levies make up a significant proportion of retail fuel prices and any changes in government taxes and levies can therefore have a significant impact on retail diesel and petrol prices. During the period analysed, there was no significant change in consumption taxes, apart from February 2010, when almost a quarter of the consumption taxes on diesel decreased. In other cases, only the classification and categorization of fuels (due to biofuels), without significant intervention in tax rates (no more than 2 %), occurred in legislative changes. The impact of the tax change on the consumption tax on diesel can be clearly seen also in the chart of the retail price for diesel. We have highlighted it by shading the graph area in the bottom graph of Figure 1.

3. Results

3.1. Co-integration Approach Results

The unit root tests of the analysed time series confirmed the non-stationarity of price variables. As a result, the condition for using the Engle-Granger procedure is fulfilled. The key results of our estimations and tests of the single equation model are shown in Tables 1 and 2. The selected parameters, their standard deviations, the test statistics and their critical values of the best model without trend and model and with restricted trend as representatives of different deterministic schemes in co-integration modelling are sufficient to support our adopted methodology and accompanying conclusions. These models have been selected from a wide range of models with the most appropriate characteristics (no autocorrelation and precisely defined dynamics).

Table 1

The Results of Estimations and Tests of Single Equation Model for Gasoline Prices

Gasoline prices	Model without trend	Model with restricted trend
	Co-integrating Equation	
crude oil	**0.0075**	**0.0079**
standard deviation	(0.0007)	(0.0004)
trend	–	**0.0002**
standard deviation	–	(0.00004)
	Engle-Granger test	
ADF of residuals	**–4.0928**	**–6.3251**
critical value	–3.33	–3.74
	Error Correction Model	
adjustment parameter	**–0.0370**	**–0.0749**
standard deviation	(0.0087)	(0.0136)
	Bounds test	
F statistics	**5.9929**	**10.0100**
critical value I(1)	4.16	5.15
	Asymmetric Error Correction Model	
irreversibility test	**1.7427**	**1.0635**
critical value	2.2318	2.2318

Note: The significant value of each statistical test is 5 %. The null hypothesis is rejected if the test statistics is greater than the critical value of bounds test and test of irreversibility and less than the critical value of ADF test.

Source: Authors' calculations.

Table 2

The Results of Estimations and Tests of Single Equation Model for Diesel Prices

Diesel prices	Model without trend	Model with restricted trend
	Co-integrating Equation	
crude oil	**0.0038**	**0.0086**
standard deviation	(0.0013)	(0.0004)
trend	–	**0.0002**
standard deviation	–	(0.00005)
	Engle-Granger test	
ADF of residuals	**–4.8993**	**–6.5777**
critical value	–4.10	–3.74
	Error Correction Model	
adjustment parameter	**–0.0467**	**–0.0686**
standard deviation	(0.0097)	(0.0121)
	Bounds test	
F statistics	**7.7574**	**10.7645**
critical value I(1)	4.85	5.15
	Asymmetric Error Correction Model	
irreversibility test	**1.6087**	**1.7147**
critical value	2.2318	2.2318

Note: The significant value of each statistical test is 5 %. The null hypothesis is rejected if the test statistics is greater than the critical value of bounds test and test of irreversibility and less than the critical value of ADF test.

Source: Authors' calculations.

The results of all the tests confirm our justification for the use of the co-integration equation for modelling the long-term relationships between pairs of prices. Likewise, it seems appropriate to include the trend in the long-term relationships for both retail prices.

However, the answer to the key issue of price asymmetry is negative in both cases. According to the results from the single equation models, Slovak retail fuel prices don't respond more quickly when the crude oil price rises than when it decreases.

As the gasoline and diesel markets are linked, we have also used vector error correction models in our analysis. The results of the analysis are in Table 3.

T a b l e 3

The Results of Estimations and Tests of Vector Error Correction Model

VECM	**Gasoline**	**Diesel**	**VECM test statistics**	
	Co-integrating equations		*Residual Portmanteau Test*	
crude oil	**0.0076**	**0.0087**	Lag(1) 1.9599	---
std. dev.	(0.0004)	(0.0004)	Lag(2) 10.0534	$\chi^2(10) = 18.307$
trend	**0.0002**	**0.0002**	Lag(3) 21.0732	$\chi^2(19) = 30.144$
std. dev.	(0.00005)	(0.00005)	Lag(4) 27.8578	$\chi^2(28) = 41.337$
	Error Correction		*Lag Exclusion Wald Test*	
adj. gasoline	**−0.0752**	**−0.0346**	**Lag(1) 124.807**	$\chi^2(12) = 21.026$
std. dev.	(0.0120)	(0.0119)	Lag(2) 14.3612	$\chi^2(12) = 21.026$
adj. diesel	**−0.0358**	**−0.0729**	Lag(3) 13.6213	$\chi^2(12) = 21.026$
std. dev.	(0.0111)	(0.0109)	Lag(4) 11.3476	$\chi^2(12) = 21.026$
VECM – test for weak exogeneity of crude oil price			*Trace statistics*	*Critical value*
restriction test	**1.1946**	$\chi^2(2) = 5.9915$	CE(0) 92.4477	42.9153
A-VECM test statistics			CE(1) 28.8114	25.8721
irreversibility test	**6.2064**		CE(2) 5.5086	12.5180
critical value	14.0671		Test indicates **2** coint. eqn(s)	

Note: The significant value of each statistical test is 5 %. The null hypothesis is rejected if the test statistics is greater than the critical value.

Source: Authors' calculations.

When looking for a final vector error correction model, we considered the lag exclusion test and the residual portmanteau test as an aid in finding an appropriate lag. The Johansen test with its lambda trace statistics indicates two co-integration equations, so we normalized the model to create one co-integrating equation for gasoline and another for diesel.

According to the proper test, we did not reject the weak exogeneity of crude oil prices. The equilibrium relations for Slovak gasoline and diesel prices cannot influence crude oil prices.

Our results from the vector error correction models are the same as the results from the single error correction models. Slovak retail fuel prices do not respond more quickly when the crude oil price rises than when it decreases.

3.2. Linex Approach Results

The estimates of the equation (10) by OLS, GMM, 2SLS, GMM1 and systems GMM methods are in Table 4. All the estimates employ both retail 95-octane gasoline prices and diesel prices. Since the residuals of the gasoline and diesel equations were statistically significantly correlated, we also estimated the equation (10) with the system GMM method. The standard errors are computed using the procedure of Newey and West.

The instrument sets applied are in the fifth column of Table 4, where the upper index denotes gasoline (G) or diesel (D) price variables. The combinations of one-period lags of the first differences of retail gasoline prices, retail diesel prices and crude oil prices are used as instruments. In the case of the forward-looking GMM equations, the not-lagged and not-leaded first differences of the crude oil price data series is used as one of the instruments. By means of the orthogonality test of instruments, we state that all used instruments are valid.

As specification (10) is nonlinear, we could not test the weakness of the instruments with Cragg-Donald F statistics and Stock-Yogo bias critical values. However, we estimated the first-stage equations for endogenous right hand side variables of the linear specification (11), i.e. Δc_t, Δc_t^2, $\Delta p_t c_t$ and Δp_t^2. They were regressed on a constant and the corresponding instrument set. All the corresponding F statistics are higher than 10, only in 4 cases are they lower than 20 but higher than 10. We consider this result to be sufficient to reject the instrument weakness.

Using the residuals, we tested the correlation of error terms of the gasoline and diesel equations. The Breusch and Pagan (1980) $\chi 2$ distributed LM statistics were computed. The values of the calculated testing statistics LM are given in the seventh column of Table 4. We do not reject the correlation between error terms in each case. Therefore, we estimated the gasoline and diesel equations as the system. The systems GMM method is used.

Estimating the system, we could compare the values of the estimated coefficients for gasoline and diesel equations. While the k coefficients are approximately equal, the estimated asymmetry coefficient γ is higher in the diesel equation. In fact, by testing the linear coefficient restrictions, we state that k coefficients of both equations equal and diesel asymmetry coefficient γ are statistically significantly higher than the gasoline one at the 1% level.

To test the endogeneity of the regressors and the weakness of the instruments, we also estimated the gasoline linear specification (11) by the systems GMM method. However, as we have five explanatory variables with a constant in (11), we could not use the same instrument set as for (10) that consisted of only two variables. The constant and the first differences of one-period lagged gasoline and oil prices, Δc_{t-1}, Δp_{t-1}, their product $\Delta(p_{t-1}c_{t-1})$ and their second powers, $\Delta(p_{t-1}^2)$, $\Delta(c_{t-1}^2)$ were used as instruments for the (11) specification estimate.

Firstly, we tested nonlinear coefficient restrictions (12), to be sure that the over-identified specification (11) fits the (10) specification. The corresponding testing statistics with $\chi 2$ asymptotic distribution and three degrees of freedom (number of restrictions) equals 1.091, so we do not reject the restrictions.

The two version of specification (11) was estimated by means of the endogeneity test. In the first one, explanatory variables of (11) were considered to be endogenous and so the original instrument set $\{\Delta p_{t-1}, \Delta c_{t-1}, \Delta(p_{t-1}c_{t-1}), \Delta(p_{t-1}^2), \Delta(c_{t-1}^2)\}$ was used. In the second one, the explanatory variables of (11) were considered to be exogenous and the original instrument set was extended by the explanatory variables. The difference in the *J* statistics with $\chi 2$ asymptotic distribution and four degrees of freedom (number of explanatory variables) equals 22.675. We reject the exogeneity of explanatory variables of (11). We state that considering explanatory variables to be endogenous in the earlier analysis applied to the nonlinear specification (10) was correct. It also suggests that the use of instrumental methods such as GMM, 2SLS and systems GMM is proper to estimate specifications (10) and (11).

The Cragg-Donald *F* statistics was computed to test the weakness of the instrument test. Its value is 6.361. We also estimated first-stage regressions – as in the analysis for linear (4) specification – to see how weak the instruments are. The corresponding *F* statistics are higher than 10, but in general they are lower compared with the first-stage regression where only two instrument variables are considered.

The results in Table 1 – 4 correspond to the analysis of the data series with different units. Crude oil prices are in euros per barrel while retail gasoline and diesel prices are in euros per litre. This choice is justified, because a conventional unit of crude oil is a barrel while a conventional unit of European retail fuel is a litre. On the other hand, it is not difficult to re-count the results so that they compare prices in the same units. The reaction coefficients reflect the average change in the price of a litre of retail fuel after the change in the price of a barrel of crude oil. These are crude oil coefficients in Tables 1 – 3 and *k* coefficients in Table 4. To obtain these coefficients (along with standard deviations) related to the oil price per litre, it is sufficient to multiply them by 159, as one barrel is about 159 litres. Changing the units of crude oil prices has no effect on the other coefficients (including test statistics).

Comparing the results for gasoline and diesel, we state that asymmetry coefficients are higher in diesel equations than in gasoline. We confirmed this statement by the linear restriction tests applied in the estimates of the system by the system GMM method. Also the estimated price biases are higher for diesel than for gasoline in all cases. This means that the "rockets and feathers" effect is higher in the Slovak diesel market.

T a b l e 4

The Results of the Estimation of Specification (10)

Method	Equation	k	γ	Instrument Set	R^2 / J	LM	Weekly Bias
OLS	*Gasoline*	0.004^{***} (0.0005)	-0.910^{***} (0.023)	---	0.994	76.465^{***}	0.0028
	Diesel	0.005^{***} (0.0002)	-1.127^{***} (0.126)	---	0.993		0.0065
GMM	*Gasoline*	0.008^{***} (0.002)	-1.128^{***} (0.113)	Δp^G_{t-1} Δc_{t-1}	0.403	106.546^{***}	0.0133
	Diesel	0.008^{***} (0.002)	-1.404^{***} (0.172)	Δp^D_{t-1} Δc_{t-1}	0.043		0.0187
GMM1	*Gasoline*	0.005^{***} (0.001)	-0.939^{***} (0.063)	Δp^G_{t-1} Δc_t	0.062	111.192^{***}	0.0043
	Diesel	0.007^{***} (0.001)	-1.301^{***} (0.130)	Δp^D_{t-1} Δc_t Δp^G_{t-1}	0.689		0.0140
2SLS	*Gasoline*	0.008^{***} (0.001)	-1.131^{***} (0.112)	Δp^G_{t-1} Δc_t	0.990	138.848^{***}	0.0136
	Diesel	0.009^{***} (0.001)	-1.458^{***} (0.165)	Δp^D_{t-1} Δc_{t-1} Δp^G_{t-1}	0.986		0.0222
System GMM	*Gasoline*	0.008^{***} (0.002)	-1.127^{***} (0.114)	Δp^G_{t-1} Δc_{t-1}	8×10^{-4}	---	0.0132
	Diesel	0.008^{***} (0.001)	-1.452^{***} (0.161)				0.0221
System GMM *(Restr.)*	*Gasoline*	0.008^{***} (0.001)	-1.190^{***} (0.100)	Δp^G_{t-1} Δc_{t-1}	0.002	---	0.0169
	Diesel		-1.419^{***} (0.143)				0.0202

Note: Three asterisks denote the statistical significance at 1% level. In the fifth column, the upper index G denotes gasoline and the upper index D denotes diesel. Weekly biases (13) in the last column are in eurocents per litre of gasoline or diesel. The systems GMM estimates with the coefficient restrictions implying that the k coefficients are the same for both gasoline and diesel equations are in the last rows.

Source: Authors' calculations.

Liu, Margaritis, and Tourani-Rad (2010), who studied retail fuel prices in New Zealand, provide a possible explanation. "The diesel price is not as competitive as that of petrol. As diesel is mainly used by the business sector, the results suggest that commercial customers are not as price sensitive as individual motorists. As a result, oil companies have been able to take advantage of the relatively inelastic demand for diesel to increase their profits." The detailed reviews of the results of the "rockets and feathers" effect analysis in the retail fuel markets around the world are provided by Grasso and Manera (2007), Honarvar (2009) and Kristoufek and Lunackova (2015).

Conclusion

The aim of our analysis is to verify that gasoline or diesel price adjustments are not the same when crude oil prices fall on world markets than if they rise.

We used the irreversible model with the correction term as the single equation model as well as the vector model for our analysis and tested the asymmetry of the reaction by comparing the parameters for these variables corresponding to the increase and the decrease in the price of crude oil on the world markets. The result of the testing did not reject the hypothesis that the reaction of gasoline and diesel prices is the same in the case of increases and decreases in crude oil prices. So, the price asymmetry analysed using classical tools and weekly data has not been confirmed in the Slovak gasoline and diesel retail market.

If the price of a barrel of crude oil increases by one euro *ceteris paribus*, the price of a litre of gasoline and diesel retail increases (with one specific exception) by about 0.008 – 0.009 euros on average. In both the ECM and VECM estimates, the linear trend is statistically significant. The average weekly increase in the price of a litre of retail gasoline and diesel is about 0.02 eurocents (0.0002 euro). This trend could correspond to the steadily growing demand for retail gasoline and diesel in the period examined. Therefore, we contend that the traditional study approach does not confirm the theory of strategic interactions between firms and their consumers. The price making is not asymmetric, and firms do not fear increasing prices if demand increases.

However, the linex approach implies the reverse results. The asymmetry parameter is statistically significant in all cases and we observed an asymmetry in price making. The estimated k coefficient roughly corresponds to the ECM and VECM estimates. Its value depends on the method used, but by systems GMM and 2SLS methods we estimate its value to be about 0.008 or 0.009. It is worth noting that the average weekly retail gasoline and diesel price bias per litre is slightly lower than the ECM and VECM trend coefficient. Its value again depends on the method used. We estimate its value to be about 0.01 – 0.02 eurocents (comparing with 0.02 estimated by the ECM and VECM models) by the systems GMM and 2SLS methods. Moreover, we state that price biases are higher for diesel than for gasoline. Using this approach, the retail gasoline and diesel price-making process corresponds to the theory of strategic interaction between a firm and its consumers.

Considering the theory of the strategic interaction between a firm and its consumers, the retail gasoline and diesel prices are made discretionally. The price maker faces different price adjustment costs in each period. By discretion, we consider the approach based on linex adjustment costs to be a better tool to test the theory of the strategic interactions between a firm and its consumers.

The theory of strategic interaction between a firm and its consumers is one of the arguments for the assumption that firms adjust prices infrequently. The assumption of price rigidity is adapted by many macroeconomic models of business cycles. Therefore, our study is valuable for the analysis of Slovak economic policy.

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