Relation of Retail Gasoline and Diesel Prices in Croatia with Crude Oil Prices on World Markets

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Abstract

According to many studies, the transmission of oil prices to retail fuel prices is asymmetric. Fuel prices react faster if oil prices rise and more slowly if oil prices fall. We use the simple and dynamic asymmetry models, error correction models, threshold autoregressive cointegration, and an approach based on the adjustment cost function in the linear-exponential form to verify the hypothesis of asymmetric reactions of gasoline and diesel prices in Croatia. The analysis uses a weekly time series of Croatian fuel prices obtained from the European Commission Weekly Oil Bulletin and BRENT oil prices from the US Energy Information Administration. Different standard econometric procedures lead to different results. Nevertheless, the approach based on the linear-exponential lost function confirmed the price asymmetries in the Croatian market.

Keywords: asymmetry; retail gasoline prices; error correction model; threshold autoregressive cointegration; linear-exponential adjustment cost function; generalised method of moments; Croatia
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Introduction

There is a common consumer complaint that retail fuel prices respond fast if crude oil prices rise but more slowly if crude oil prices fall. This asymmetric transition of input prices to output prices in the retail fuel market has been confirmed by many studies, beginning with Bacon (1991).

Among the first European studies dealing with asymmetric responses of retail prices was Lanza (1991), who confirmed asymmetric responses of retail prices to wholesale gasoline prices. In recent works, the authors confirmed asymmetric reactions in different European countries.

Apergis & Vouzavalis (2018) confirmed short-term asymmetric adjustment of retail gasoline prices to changes in crude oil prices on the Italian market and short- and long-term on the Spanish market. Torrado and Escribano (2020) confirmed the asymmetry in the Spanish and German markets. Bragoudakis et al. (2020) showed evidence of the asymmetric markup creation by Greek refineries in response to world crude oil price changes. This asymmetry is further transmitted to retailers and consumers. However, Bragoudakis and Sideris (2021) did not confirm asymmetric adjustments of gasoline prices to oil price changes in the Greek market after 2010. Genakos and Pagliero pointed out that consumers in isolated islands with less competition faced asymmetric responses of retail gasoline prices to unannounced and non-negligible increases in consumer taxes in 2010. Čipčić (2021), in research on reactions of retail fuel prices to changes in crude oil prices in Croatia, Czech Republic, Hungary, Slovenia, Slovak Republic, and Poland, confirmed asymmetries in the short period between 2009 and 2013 in 33.33% of the analysed cases. Szomolányi et al. (2020) confirmed asymmetric retail fuel price adjustment on crude oil price changes in Slovakia.

We adapted the paper structure to the breadth of methodological procedures with several diverse econometric models. We have created a section for each method containing the estimation results using European Commission Weekly Oil Bulletin (Croatian retail gasoline and diesel prices) and US Energy Information Administration (BRENT crude oil prices) data. We combined the discussion and conclusion in the final section.

Simple Models of Asymmetry

We start with the simple model of asymmetry, similar to Tweeten & Quance (1969):

$$y_t = \beta_0 + \gamma_0^+ x_t^+ + \gamma_0^- x_t^- + u_t \tag{1}$$

where y_t is regressand and the average weekly price of gasoline or diesel in time t; x_t^+ is the average weekly price of oil in time t equals x_t if its value has increased over the last period and zero otherwise and x_t^- is the average weekly price of oil in time t equals x_t if its value has decreased over the last period and zero otherwise.

We can continue with a model with another regressor (the price of another fuel z_t – the gasoline price in the equation of diesel price and vice versa):

$$y_t = \beta_0 + \gamma_0^+ x_t^+ + \gamma_0^- x_t^- + \delta_0 z_t + u_t \tag{2}$$

Asymmetry in models (1) and (2) is present if the null hypothesis of $\gamma_0^+ = \gamma_0^-$ is rejected. The F test can test this linear hypothesis in the linear model.

We can also consider more dynamic models, similar to Karrenbrock (1991):

$$\Delta y_t = \beta_0 + \sum_{i=0}^{s} \gamma_i^+ \Delta x_{t-i}^+ + \sum_{i=0}^{q} \gamma_i^- \Delta x_{t-i}^- + u_t \tag{3}$$

where the cumulative effect of price variation can be tested with the hypothesis: $\sum_{i=0}^{s}\gamma_i^+ = \sum_{i=0}^{q}\gamma_i^-$

Table 1 shows the coefficient estimates and asymmetry tests of the (1)-(3).

Table 1
Simple and Dynamic Models of Croatia's Fuel Prices Asymmetry

Simple Models	γ_0^+	γ_0^-	δ_0	Symmetry
gasoline model (1)	0.3840***	0.3953***	---	***F* = 6.182****
(std. err.)	(0.050)	(0.053)	---	**[0.013]**
diesel model (1)	0.3514***	0.3620***	---	*F* = 3.095*
(std. err.)	(0.064)	(0.069)	---	[0.079]
gasoline model (2)	0.1031**	0.1089**	0.5966***	***F* = 4.413****
(std. err.)	(0.045)	(0.046)	(0.016)	**[0.036]**
diesel model (2)	0.0670**	0.0693**	0.8083***	*F* = 0.119
(std. err.)	(0.030)	(0.032)	(0.185)	[0.731]
Dynamic Models – 1 Lag	**Symmetry**	**Dynamic Models – 2 Lags**		**Symmetry**
gasoline model (3)	*F* = 1.001	gasoline model (3)		*F* = 0.424
	[0.318]			[0.515]
diesel model (3)	*F* = 0.024	diesel model (3)		*F* = 0.915
	[0.878]			[0.393]
Dynamic Models – 3 Lags	**Symmetry**	**Dynamic Models – 4 Lags**		**Symmetry**
gasoline model (3)	*F* = 0.584	gasoline model (3)		*F* = 2.634
	[0.445]			[0.105]
diesel model (3)	*F* = 0.342	diesel model (3)		*F* = 0.177
	[0.559]			[0.674]

Note: Three asterisks indicate statistical significance at the 1% significance level, two at the 5%. A bolded result means the rejection of symmetry. The probability values are in square brackets.
Source: Authors' calculations

Error Correction Models

We continue with the auto-regressive distributed lag model of order one with two variables:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \gamma_0 x_t + \gamma_1 x_{t-1} + u_t \tag{4}$$

and then with three variables:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \gamma_0 x_t + \gamma_1 x_{t-1} + \delta_0 z_t + \delta_1 z_{t-1} + u_t \tag{5}$$

where y_t is the average weekly price of gasoline or diesel in time *t*; x_t is the average weekly price of oil in time *t*; z_t is another relevant regressor in time *t* (the price of another fuel); 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 (4) as the error correction model (Engle & Granger, 1987):

$$\Delta y_t = \beta_0 + \gamma_0 \Delta x_t + (\beta_1 - 1)\left[y_{t-1} - \frac{(\gamma_0+\gamma_1)}{1-\beta_1} x_{t-1} \right] + u_t \tag{6}$$

and model (5) as the error correction (ECM) model:

$$\Delta y_t = \beta_0 + \gamma_0 \Delta x_t + \delta_0 \Delta z_t + (\beta_1 - 1)\left[y_{t-1} - \frac{(\gamma_0+\gamma_1)}{1-\beta_1} x_{t-1} - \frac{(\delta_0+\delta_1)}{1-\beta_1} z_{t-1} \right] + u_t \tag{7}$$

which contains the original (one period-lagged) variables in the levels and their first differences. Suppose a positive unit change of the regressor has an identical influence on the regressand as a negative unit change. In that case, we do not have to distinguish between them. We can estimate the overall response with one parameter for one regressor, as in the reversible models (6) and (7). If this restriction is not valid, the estimation results can be improved by specifying increases ($\Delta^+ x_t$ and $\Delta^+ z_t$) and decreases ($\Delta^- x_t$ and ($\Delta^- z_t$) of the explanatory variables as separate variables and also by separating the positive and negative deviations from the long-run equilibrium relationship.

The asymmetric irreversible error correction model (Granger & Lee, 1989):

$$\Delta y_t = \beta_0 + \gamma_0^+ \Delta^+ x_t + \gamma_0^- \Delta^- x_t + \lambda^+ e_{t-1} \times D(e_{t-1} > 0) + \lambda^- e_{t-1} \times D(e_{t-1} \le 0) + u_t \quad (8)$$

where $e_{t-1} = y_{t-1} - \frac{(\gamma_0 + \gamma_1)}{1-\beta_1} x_{t-1}$ is one period-lagged deviation from the long-run equilibrium relationship; $D(e_{t-1} > 0)$ is a dummy variable that equals one if $e_{t-1} > 0$ and equals zero otherwise; $D(e_{t-1} \le 0)$ is a dummy variable that equals one if $e_{t-1} \le 0$ and equals zero otherwise; λ^+ and λ^- are the corresponding adjustment parameters.

and then the asymmetric irreversible error correction (A - ECM) model:

$$\Delta y_t = \beta_0 + \gamma_0^+ \Delta^+ x_t + \gamma_0^- \Delta^- x_t + \delta_0 \Delta z_t + \lambda^+ e_{t-1} \times D(e_{t-1} > 0) + \lambda^- e_{t-1} \times D(e_{t-1} \le 0) + u_t \quad (9)$$

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 one if $e_{t-1} > 0$ and equals zero otherwise; $D(e_{t-1} \le 0)$ is a dummy variable that equals one if $e_{t-1} \le 0$ and equals zero 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.

Table 2
Error Correction Models of Croatia's Fuel Prices Asymmetry

Cointegration Models	Engle-Granger	Cointegration Models	Engle-Granger
gasoline model (4)	**τ = -4.429*** **	**gasoline model (5)**	**τ = -4.377*** **
gasoline model (4) + trend	**τ = -5.832*** **	**gasoline model (5) + trend**	**τ = -4.662** **
diesel model (4)	τ = -2.991	diesel model (5)	τ = -2.939
diesel model (4) + trend	**τ = -5.328*** **	diesel model (5) + trend	τ = -3.253
Asymmetric ECM	**LR Symmetry**	**SR Symmetry**	**Both Symmetries**
gasoline model (8)	*F* = 0.738	*F* = 0.537	*F* = 1.268
gasoline model (8) + trend	*F* = 0.072	*F* = 1.711	*F* = 0.924
gasoline model (9)	*F* = 0.017	*F* = 3.232*	*F* = 1.629
gasoline model (9) + trend	*F* = 0.006	*F* = 3.255*	*F* = 1.704
diesel model (8) + trend	*F* = 0.926	***F* = 5.199** **	*F* = 2.665*

Note: Three asterisks indicate statistical significance at the 1% significance level, two at the 5%. A bolded Engle-Granger test result means the rejection of symmetric cointegration. A bolded F test results mean the rejection of long-run (LR), short-run (SR) or both symmetries.
Source: Authors' calculations

Models (6) and (7) are obtained from models (8) and (9) using restrictions $\lambda^+ = \lambda^-$ and $\gamma_0^+ = \gamma_0^-$. In cases where models (4) and (5) have a more extensive dynamic structure, models (8) and (9) will also be more extensive. The test hypothesis will additionally include parameter comparisons for other lags.

Table 2 shows the coefficient estimates and asymmetry tests of the (4)-(9).

Threshold Autoregressive Cointegration

Engle & Granger's (1987) approach is based on a symmetric long-run relationship. A different solution to the problem than Granger & Lee (1989) was proposed by Enders & Granger (1998), who introduced Threshold Autoregressive Cointegration. If the adjustment to the long-run equilibrium is asymmetric, the cointegration test is misspecified. To overcome the problem, Enders & Siklos (2001) replace the standard augmented Dickey-Fuller test equation with the following threshold autoregressive process:

$$\Delta e_t = I_t \rho_1 e_{t-1} + \left(1 - I_t\right) \rho_2 e_{t-1} + \varepsilon_t \tag{10}$$

where e_t is the deviation from the long-run equilibrium relationship (residual).

If the errors are serially correlated, equation (10) can be augmented with the lagged differences of e_t as in the standard augmented Dickey-Fuller test.

Indicator function I_t is defined to depend on the lagged values of the residuals, according to the following scheme:

I_t equals one if $e_{t-1} > 0$ and equals zero otherwise (11)

alternatively, it is defined to depend on the lagged values of the first differences of residuals:

I_t equals one if $\Delta e_{t-1} > 0$ and equals zero otherwise (12)

The relationships (10) and (11) are called TAR cointegration. In contrast, the relationships (10) and (12) are known as momentum TAR (or M-TAR) cointegration. In M-TAR models, the threshold is placed on the variation of e_{t-1} rather than on e_{t-1}.

The null hypothesis $\rho_1 = \rho_2 = 0$ of no cointegration can be tested through an F test. The adjustment is symmetric for nonzero $\rho_1 = \rho_2$; thus, the Engle-Granger approach is a special case of (10) and (11).

Table 3
TAR and M-TAR Models of Croatia's Fuel Prices Asymmetry

TAR Models	$\rho_1 = \rho_2 = 0$	$\rho_1 = \rho_2$	M-TAR Models	$\rho_1 = \rho_2 = 0$	$\rho_1 = \rho_2$
gasoline	**F = 7.010*** **	F = 0.462	gasoline	**F = 5.842*** **	F = 0.558
gasol. + trend	**F = 12.10*** **	F = 0.105	gasol. + trend	**F = 8.887*** **	F = 0.280
diesel	**F = 4.560** **	F = 0.006	diesel	F = 1.896	F = 0.614
diesel + trend	**F = 5.349*** **	F = 0.055	diesel + trend	**F = 4.621** **	F = 0.015
Cross Models			Cross Models		
gasoline	**F = 5.679*** **	F = 0.001	**gasoline**	**F = 10.06*** **	**F = 8.255*** **
gasol. + trend	**F = 6.955*** **	F = 0.016	**gasol. + trend**	**F = 9.203*** **	**F = 6.423** **
diesel	**F = 4.292** **	F = 2.133	diesel	F = 3.010*	F = 0.549
diesel + trend	**F = 3.737** **	F = 0.097	diesel + trend	**F = 4.389** **	F = 0.327

Note: Three asterisks indicate statistical significance at the 1% significance level, two at the 5%, and one at the 10%. A bolded F test result represents the rejection of null hypothesis.
Source: Authors' calculations

In the case of the rejection of null hypothesis in (10), the analysed variables are cointegrated, and the asymmetric ECM representation can be written as:

$$\Delta y_t = \lambda_{up} e_{t-1}^{up} + \lambda_{down} e_{t-1}^{down} + \sum_{i=0}^{p} \gamma_i \Delta x_{t-i} + \sum_{i=0}^{r} \delta_i \Delta z_{t-i} + \sum_{i=1}^{s} \alpha_i \Delta y_{t-i} + u_t \tag{13}$$

where $e_{t-1}^{up} = I_t e_{t-1}$, $e_{t-1}^{down} = (1 - I_t) e_{t-1}$. When ρ1 is less than ρ2, the increases tend to persist, whereas the decreases tend to revert quickly toward equilibrium.

Table 3 shows the coefficient estimates and asymmetry tests of the (10)-(13).

Adjustment Cost Function in Linear-Exponential Form

From the linear-exponential cost function, it is possible to derive price response functions for a given fuel and a given country represented by an econometric system of equations in the form (Szomolányi et al. 2020 and 2022):

$$\Delta p_t = k \Delta c_t - \frac{1}{2} \gamma \Delta \left[\left(p_t - k c_t \right)^2 \right] + u_t \tag{14}$$

where Δ denotes the first difference operator, p_t is the output (gasoline or diesel) price, c_t is the input (crude oil) price, u_t is a stochastic term, k is the technology coefficient, and γ is the asymmetry coefficient. If the output price reactions are excessive when the input price rises and mild when the input price falls, then the negative value of the asymmetry coefficient γ is assumed. When γ = 0, the reaction function specification is linear, and the output prices react on the input price changes symmetrically.

The changes in the input prices Δc_t are a normally distributed process with zero mean and variance σ^2. The estimates of the average price biases are (Szomolányi et al. 2020 and 2022):

$$E(\Delta p_t) = -\frac{k^2 \gamma}{2} \sigma^2 \tag{15}$$

The orthogonality conditions implied by the rational expectation hypothesis make the GMM a natural candidate to estimate the (14). Standard errors have been computed using the Newey-West procedure. The most important feature of the procedure explained by Newey & West (1987) is its consistency in the presence of both heteroskedasticity and the autocorrelation of unknown forms.

Table 4 shows the coefficient estimates of the (14) and the bias estimate (15).

Table 4

Results of the Linear-Exponential Adjustment Cost Function Approach

GMM Models	k	γ	J	Bias
gasoline	1.5789***	–0.0012***	0.521	**0.3145**
(std.err.)	(0.186)	(0.0001)	[0.470]	
diesel	1.4698***	–0.0009***	0.00001	**0.2122**
(std.err.)	(0.392)	(0.0002)	[0.997]	

Note: Three asterisks indicate statistical significance at the 1% significance level. A bolded J test result means the rejection of orthogonality. The probability values are in square brackets.
Source: Authors' calculations

Conclusion

As Deltas and Polemis (2020) argue, testing asymmetric price transition depends a lot on the design of the model. Different standard econometric procedures used in our paper, such as the simple asymmetry model, error correction model, and threshold autoregression, also lead to different results. Nevertheless, the approach based on the linear-exponential lost function confirmed the price asymmetries in both Slovak (Szomolányi et al. 2020) and Croatian markets.

In the case of simple asymmetry models, asymmetry was indicated for gasoline prices in the simple model depending on oil price increases and decreases, but also in the model when we added the price of diesel. On the other hand, diesel prices in simple models did not show any asymmetry.

The Engle-Granger procedure showed the existence of cointegration between variables in all gasoline price models but only in the diesel price trend model without additional explanatory variables. Therefore, we only constructed an asymmetric irreversible error correction model for these cases. This time, no asymmetry was evident in any gasoline model, and only short-term asymmetry was observed in the diesel price model.

Threshold Autoregressive Models indicated no asymmetry, and Momentum Threshold Autoregressive Models show asymmetry in gasoline price models with trendless and trended diesel price explanatory variables.

Finally, we also checked the asymmetry using the linear-exponential adjustment cost function approach proposed by Szomolányi et al. (2020) for Slovakia and replicated for the US cities in Szomolányi et al. (2022). As a result, we confirmed asymmetry for both fuel prices, and we calculated bias values, which are 0.3145 for gasoline and 0.2122 for diesel.

Our results contradict Čipčić's (2021), who did not confirm asymmetric retail gasoline and diesel reactions on crude oil changes in Croatia.

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