Liquid fuel price adjustment in Greece: a two-stage, threshold cointegration approach[1]

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Abstract

In Greece, there is a widespread belief among consumers that fuel prices in the domestic market respond faster to crude oil price increases than decreases and they attribute this pricing pattern to exploitation of market power on behalf of the companies. This article attempts to investigate the issue of asymmetries in a two-stage price-adjusting mechanism able to identify the source of price asymmetries, either in the refining or in the distribution stage. The sample consists of daily data covering the period of January 2012 to November 2018 and has been split into two subsamples due to a structural break in October 2014. Employing threshold and momentum models of cointegration at the two stages linking crude oil to retail prices, we find that transmission is mostly symmetric for unleaded95 gasoline between 2012 and 2014 and asymmetric in the stage of refining for diesel. Between 2014 and 2018 asymmetry exists for both types of fuel in the refining stage, while the retail market presents symmetric pricing.

Keywords: Asymmetry, Rockets and feathers, Error-correction models, Threshold cointegration, Fuel price

JEL Classification numbers: Q40, C32, L11

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Abstract

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1. Introduction

Greek consumers have been regularly complaining about unreasonably high prices of retail liquid fuels like gasoline and diesel. These issues have become subject of extensive public discourse depicted in numerous articles in the press and reports on television. Most of them focus on cases of fuel adulteration and government taxation. The latter, in February 2019, according to the European Commission constitute approximately 67% and 51% of the consumer price at the pump for unleaded 95 gasoline and diesel, respectively. For the Unleaded 95 gasoline Greece has the second highest percentage of taxation as share of the final consumer price, where the 51% in the Diesel is below the EU average of 55%. However, little attention is paid to the efficiency of the market in terms of competition and the existence of potential oligopolistic behavior of oil companies. Under these circumstances, the oil companies often collude in defining fuel prices. Thus, retail fuel prices usually respond faster to input cost increases compared to cost reductions. For this reason, in this paper we attempt to investigate the adjustment dynamics between prices of liquid fuels and international oil prices in. We focus on unleaded95 gasoline and diesel as they constitute the main oil products in Greece.

The host of the literature analyzed the adjustment path between crude oil and retail gasoline or diesel prices as a single stage process (Al-Gudhea et al., 2006, Asane-Otoo and Schneider, 2015). Nevertheless, this assumption is relatively oversimplified as the sector has a structure characterized by complexity, with country-specific peculiarities. In this paper we attempt to move beyond this and assume the existence of two stages in the production and distribution process: the first one includes the refining process whereby crude oil is transformed into the refined product, while the second one concerns the distribution of gasoline or diesel to fuel filling stations and the formation of price at the pump. Therefore, prices used in the initial stage are crude oil price and ex-refinery price, while the following stage analyzes the dynamics between ex-refinery and retail prices. We believe that this strategy accounts for a more sensible and realistic representation of the chain connecting crude oil to retail prices. Thus, that it is of great interest to identify whether the source of asymmetry originates in upstream[2] or in downstream[3] phase of the price-transmission process. In the case of non-competitive behavior on behalf of the companies that disrupts market equilibrium and leads to increases in retail liquid fuel prices, the two-stage nature of our investigation is clearly useful. Moreover, this issue is of utmost importance for Greece since the domestic oil production is almost negligible, the domestic demand is essentially covered by imports and international crude oil prices are clearly exogenous. Additionally, the price of crude oil captures the public's interest, making the connection between the cost of inputs and the price of outputs quickly noticeable consumers. This paper is novel in the way that it uses for the first time in the analysis of the Greek liquid fuel market a daily dataset that covers the volatile period of 2012 to 2018. Making use of threshold autoregressive models of cointegration at different stages of the price transmission chain, we provide evidence that the pass-through of the price is in principal symmetric for the period between 2012 and 2014 for unleaded95 gasoline while asymmetry can be identified in diesel's refining stage. Between 2014 and 2018 the refining stage presents evidence of asymmetric price adjustment for both fuels while the retail market functions competitively.

The remainder of the paper is organized as follows: Section 2 describes the structure and the characteristics of the oil sector in Greece, and section 3 provides the theoretical perspective of the price asymmetries in oil markets. Section 4 offers a brief overview of the relative literature, section 5 describes the data and introduces the econometric approach, while

[2] An **upstream price** is the price of one of the main inputs of production or a price quoted on higher market levels (e.g. wholesale markets). Upstream prices are the prices paid by producers and are directly related to the cost of production.

[3] **Downstream prices** are the prices paid by consumers at the retail level.

the results are presented and discussed in chapter 6. Finally, section 7 offers concluding remarks and discusses potential policy implications.

2. **Structure of the Greek liquid fuel market** [4]

2.1 Oil Refining

At the refining stage, crude oil is imported from the oil-producing countries and after being refined in domestic units, it is either sold in the Greek market or exported. Two refining companies operate in the Greek market, Hellenic Petroleum S.A. and Motor Oil Hellas S.A, with four refineries operating in total in the country. Hellenic Petroleum according to its 2018 financial report operates three refineries which account for approximately 65% of the country's total refining capacity. According to the financial report of Motor Oil for the year of 2018, the company had a market share of 45,4% for gasoline and 28,3% for Automotive and Heating Diesel. These data essentially mean that almost the whole of the domestic demand is covered through these two companies. That is also in line with the study of Polemis (2012) which states that almost a decade ago in the refining market, Hellenic Petroleum and Motor Oil Hellas covered almost 90% of the domestic demand.

2.2 Wholesale Trading of Petroleum products

The second stage of the market for petroleum products includes wholesalers who receive the refined products from domestic refineries, whereas sometimes they also import fuel directly from foreign markets. Then from their warehouses the trading companies can either export or supply fuel to other wholesalers, holders of a retail trading license, large final consumers. According to the International Energy Agency (IEA), over 53 companies operate in Greek's wholesale petroleum sector, holding 80 licenses. To stimulate competition and encourage economic growth, Greece has reduced entry barriers into the downstream petroleum market. Recent legislation has reduced the minimum capital and storage capacity required for applicants for an oil trading license. Hellenic Petroleum holds a dominant position in this segment too.

2.3 Retail fuel filling stations

Retail fuel filling stations can be divided into:

[4] The content of this section is based on the sector study of ICAP for liquid and gas fuels (Athens 2017) and data from the "Energy policies of IEA countries, Greece 2017 Review".

1. Stations with the trademark of one of the trading companies and are supplied exclusively by it.
2. Independent outlets, which are not branded and can be supplied with fuel either directly from refineries or from trading companies.

In Greece, according to figures from the Pan-Hellenic Federation of Fuel Station Operators, it is estimated that at the end of 2015 the number of service stations was around 5,000 against the higher figure of 8,500 in 2012. Hellenic Petroleum and Motor Oil, which operate various brands, dominate the retail market too. Hellenic Petroleum merged its two retail companies (EKO and Hellenic Fuels) in 2016 into one company (EKO Hellenic Fuels and Lubricants Industrial and Commercial), which accounts for over 30% of the market. The retail operations of the merged company continue under the earlier branding logos of EKO and BP. Motor Oil transferred the retail assets of one of its subsidiaries (Cyclon Hellas) to another subsidiary (Avin Oil) in 2015. The combined retail business accounts for about 12.47% of the market share for 2018. Motor Oil is also the owner of the Shell network, which accounts for about 20% of the retail market and is the leader in automotive gasoline retailing. In the overwhelming majority of service stations, the final price at the pump is determined by the station's operators. The price that refinery stations charge wholesale oil companies for the fuel sold will henceforth be mentioned as ex-refinery price. The price charged for the fuel by the refiner or the wholesale company to the independent and branded petrol stations respectively is named wholesale price and to a large extent it is the price that the consumer realizes at the pump, named as retail price.

3. Price asymmetries in fuel markets: The theoretical framework

Economic literature indicates that price rigidity is a prerequisite for the existence of asymmetric effects in price transmission which prevents instant or quick adjustment of downstream prices to shocks occurred in the upstream level. However, according to Peltzman (2000) "economic theory suggests no pervasive tendency for prices to respond faster to one kind of cost change than to another". Nevertheless, several more or less standard theoretical explanations could provide the foundations for the support of the "rockets and feathers" hypothesis. Initially, a representative firm, which intends to the maximization of its profit, in a competitive market with absence of any restrictions, would instantaneously and probably symmetrically adjust its price to the variation in its input cost. This could depict the reality when imperfections are absent from the market structure. Nevertheless, immediate price adjustment could be also undermined by menu costs even in the case that market power of the firm is restricted. In a similar manner, inventory valuation and accountancy rules may be accountable for the unresponsiveness in the adjustment of downstream prices to input cost fluctuations. Market power is presumably the major worry to those who ascertain that fuel prices are unable to respond in the same manner and adjust quickly to oil price fluctuations. The main argument has the following rationale. Retail fuel filling stations reputedly attempt to sustain their "normal" profit margins in input cost increases, but they try to secure the greater margins that result, transitory, when upstream prices decrease. In any case, this state is temporary because, exempli gratia, consumer search costs exist. At the time when highly priced search is finished by consumers, profit margins and prices tend converge to the equilibrium point that the competitive market indicates.

Another version of this story epitomizes the tacit collusion that is present when market concentration exists. At the time of an increase in upstream price, each firm is rapidly reacting by rising its selling price so as to communicate to its competitors that it is dedicated to the tacit agreement; on the contrary when input cost falls, it is slowly harmonizing its price due to the risk of disseminating a signal that is strategically escaping from the agreement by trimming its margins. A different theoretical justification is the fact that adjusting the production to price variations implies extra cost. According to Grasso and Manera (2007), when a cost shock takes place, competitive firms with profit-maximizing behavior respond and mitigate part of the shock by depleting inventories in upstream price decreases and storing output when they increase. This implies delays in the adjustment of downstream prices to cost shocks even in competitive markets, even though it is also in congruence with firms exploiting market power.

Another potential source of asymmetric adjustment especially in the second stage of distribution is the lack of ability on behalf of the consumer to treat retail fuels as homogenous product; and therefore, the only determinant for the choice of the retailer to be the price. In reality, the selection of the retail store is sometimes dependent on the trust to the retailer, the brand name of the store, the advertisement or any other loyalty cards and small gifts that retail fuel stores usually offer. Peltzman (2000) also states that neither inventory holdings nor menu costs are the main factors that generate price asymmetries. In principal, "rockets and feathers" hypothesis is a symptom of dysfunctionalities in competition, such as oligopolistic market structure.

4. Overview of the literature

A sizable segment of the literature has analyzed the property of key economic variables, such as real GDP, unemployment, and industrial production, to follow asymmetric adjustment paths over the business cycle. Neftci (1984) argued in favor of the asymmetric behavior of U.S. unemployment over the business cycle whereas Falk (1986) found little evidence supporting the asymmetries when he applied Neftci's methodology to GNP, investment and productivity of the United States and to the productivity of several industrial countries. More recently, Xue and Zhang (2019) find evidence for asymmetric effects of bank credit on the business cycle. Bacon (1991) was pioneer in developing a methodology suitable for testing whether the adjustment paths of retail fuel prices with the price of gasoline as sold by refineries are asymmetric (but limited to the second stage of the distribution) in the United Kingdom, naming this phenomenon as "rockets and feathers". Under these circumstances the retail prices of gasoline shooting up like rockets for positive oil price movements and floating downward like feathers as a reaction to negative oil price shocks. There is extensive literature that examines the phenomenon of asymmetric behavior of retail fuel prices to changes in either crude oil prices or wholesale fuel prices. This literature is differentiated according to the following factors: the time period that the dataset covers and the frequency of the data; the country examined; the econometric model employed in the empirical examination; the segmentation of the chain linking crude oil prices to retail prices to multiple stages or the consideration of it as a single stage process.

Karrenbrock (1991) uses a monthly dataset from 1983-1990 to analyze empirically the relationship between U.S. wholesale and (after tax) retail gasoline prices. The findings suggest that although wholesale price increases are reflected faster to retail prices for leaded and unleaded gasoline, eventually wholesale price decreases are fully transmitted in the retail prices. Boreinstein et al. (1997) using a dataset of weekly and semimonthly data for the US gasoline market examined the hypothesis that retail prices respond faster to crude oil price increases than to decreases. Splitting the distribution chain into multiple stages the authors go beyond the proof of existence of asymmetric price transmission and they attribute the phenomenon to the adjustment of spot gasoline markets to crude oil price changes amongst else.

Numerous studies examine the "rockets and feathers" phenomenon in the US. These studies differentiate mostly in the econometric methodology employed and the time frame of the data (Al-Gudhea et al., 2007, Douglas, 2010). Deltas (2008) examines panel data (US state market data from 1988 to 2002) and Blair et al. (2017) employ regional data from 2000 to 2016 to test for the asymmetric adjustment hypothesis. Both studies find evidence for widespread asymmetries. In contrast, Bumpass et al. (2015) using U.S. city average retail price for unleaded gasoline from 1976 to 2012 argues in favor of long-run symmetric response of gasoline prices at the retail and wholesale stages. The authors claim that asymmetric findings may be sensitive to the cointegration method employed. Finally, Polemis and Tsionas (2016) using for the first time nonlinear semiparametric models with local Generalized Method of Moments (GMM) confirm the hypothesis of "rockets and feathers" for the US market and they indicate as potential source of asymmetries the oligopolistic market structure along with the shocks in spot gasoline and inventory price.

Several studies use international data. Galeotti et al. (2003) make an international comparison between the markets of Germany, France, UK, and Italy to test for the "rockets and feathers" hypothesis. Using the methodology of an asymmetric error-correction model, the pass-through of oil price to gasoline prices is examined in two stages, roughly equivalent to an initial refining stage and subsequently to a distribution stage, to determine the source of asymmetry. Additionally, Galeotti et al. (2003) allow for a potential asymmetric role of the exchange rate, as crude-oil transactions take place in dollars whereas retail price are expressed in national currencies. In summary, Galeotti et al. (2003) find that price adjustment mechanism is characterized by extensive price asymmetries in many European countries. Several studies consider the exchange rate as possible source of asymmetry for the Eurozone area and investigate its role in the price pass-through (Polemis and Fotis, 2013, Lamotte et al., 2013, Chen et al., 2019).

Manera and Grasso (2005) conduct a comparative study of the three most widely-used models developed to capture asymmetric price adjustment, namely, ECM with threshold cointegration, asymmetric ECM, and autoregressive threshold ECM. All the three models are tested on a common dataset for the gasoline markets of France, Germany, Italy, Spain and UK in a period covering from January 1985 to March 2003. The transmission of changes in upstream prices to downstream prices is investigated at different stages of the process of price formation. All models capture a temporal delay in the adjustment of retail prices to changes in spot gasoline and crude oil prices and additionally provide some evidence of asymmetric behavior. However, the findings on the asymmetric behavior in the oil-gasoline price adjustment heavily depend on the model.

More recent studies of the European markets provide mixed results on asymmetric behavior, depending on the country, the econometric model, and the time frame. Karagiannis et al. (2015) using a dataset from 2002 to 2011 employ a "decomposed" error-correction model to test for the presence of asymmetries in the markets of Germany, France, Italy and Spain considering the transmission as single stage process from crude oil to retail prices. Empirical results indicate that symmetric adjustment dominates across the afore mentioned markets. Using a micro-econometric approach for Turkey, Özmen and Akçelik (2017) find evidence for positive asymmetry of the pass-through of crude oil on the diesel price but no asymmetry in the case of gasoline.

Apergis and Vouzavalis (2018) make a comparative analysis of pass-through of crude oil to gasoline prices for the markets of US, the UK, Spain, Italy, and Greece. The authors using a nonlinear autoregressive distributed lags (NARDL) model explore the adjustment dynamics of oil prices to gasoline prices in a period between January 2009 and July 2016. Moreover, the authors approximated the responses to positive and negative oil price shocks by constructing asymmetric dynamic multipliers. The results indicate differences regarding the adjustment of gasoline prices to crude oil prices. The Italian market is characterized by short-run asymmetry, whereas in the Spanish market both short- and long-run asymmetry has been observed. The Greek market presents similar evidence with U.K. and U.S. in terms of retail gasoline price adjustment that is in principal symmetric. A similar econometric methodology is used by Bagnai and Ospina (2016) for the Eurozone countries. The authors find evidence for negative asymmetry on the effects of crude oil prices on gasoline prices as predicted by endogenous mark-up models. In other words, crude oil price reductions have a greater effect than price increases on gasoline prices. This effect differs between core and peripheral Eurozone countries.

Lastly, some studies focus on specific countries. Lamotte et al. (2013) use the ARDL bounds test for cointegration and find evidence for asymmetric response of gasoline prices to crude oil price changes. Asana-Otoo and Schneider (2015) investigate the adjustment dynamics of diesel and gasoline retail prices to international crude oil prices in Germany. They find price patterns that indicate positive asymmetries for both gasoline and diesel within the period 2003–2007. On the contrary, for 2009–2013, they conclude that the pass-through of the price is mostly symmetric for retail diesel, whereas gasoline prices are characterized by negative asymmetries.

4.1 The case of Greece

Angelopoulou and Gibson (2010) use Greek data and specifically to the relationship between retail prices of petrol and diesel and international crude oil prices while incorporating in their analysis the component of the amount of taxes. They investigate not only the hypothesis that there is asymmetric adjustment of petrol and diesel prices to international crude oil movements and the pass-through rates of tax increases, but additionally they exploit the cross-sectional aspect of the data to examine whether market power can influence retail prices. The results suggest that the pass-through of the price is mostly symmetric. However, overreaction of price to tax changes can be noticed to specific regions across the country where market power is concentrated, and the market presents imperfections in terms of competition.

Polemis (2012) attempts to examine the presence of asymmetric price patterns in the transmission of shocks to input cost prices and exchange rate onto the wholesale and retail price of gasoline, respectively. For this purpose, the author employs the error-correction methodology in the Greek market and tries to explain the effect of competition on the dynamic adjustment of gasoline price by using impulse response functions. The dataset consists of monthly observations starting from January 1988 up to June 2006. The findings suggest that retail gasoline prices behave asymmetrically to shocks in upstream prices both in long and short-term. At the wholesale stage, the author observes asymmetric reaction of the spot prices of gasoline towards the adjustment to the short-run responses of the exchange rate. Evidence shows that after 1992 when deregulation legislation was passed, wholesale prices of gasoline tend to progressively revert to the equilibrium more quickly compared to the previous period.

Bragoudakis et al. (2019) depart from the conventional cointegration techniques in fuel prices and examine the competitiveness of the Greek fuel market testing for asymmetries in refineries' and retailers' mark-ups. Their sample period coincides partially with our paper as their dataset covers the period between January 2014 and April 2018. Their evidence supports asymmetric behavior on behalf of the refineries for diesel and gasoline fuel, while for the retail segment of the market the evidence indicates competitive behavior.

5. Empirical methodology

5.1. Threshold cointegration

Once we establish the integration property of each of the price series, we employ the Enders and Siklos (2001) threshold cointegration approach to test for the non-linear price relationships between retail and upstream fuel prices. The Enders and Siklos (2001) test draws on the Engle and Granger (1987) approach of symmetric price transmission and considers regime switching cointegration allowing for possible asymmetries. The test focuses on (i) the residuals from the estimation of the long-run equilibrium relationship for the first stage that corresponds to the refinery process and (ii) the residuals from the estimation of the long-run equilibrium relationship of the distribution stage. All the series are integrated of order one. The cointegrating relationship for "Stage 1" is given by equation (1):

$$P_t^{ref} = a_0 + a_1 P_t^{brent} + a_2 ER + u_t \qquad (1)$$

and for "Stage 2" by equation (2):

$$P_t^{retail} = a_3 + a_4 P_t^{ref} + \varepsilon_t \qquad (2)$$

The interpretation of the variables involved in the equations above is as follows: P_t^{ref} is the ex-refinery price of Unleaded95 gasoline or diesel at time t, P_t^{brent} is the price of Brent crude in dollars, ER is the U.S. dollar / Euro exchange rate defined as number of dollars per euro, and P_t^{retail} is the retail price for Unleaded95 gasoline/diesel at time t. a_0, a_1, a_2, a_3 and a_4 are coefficients while u_t, ε_t are the residuals in equations (1) and (2), respectively, which capture the gap from the long-run equilibrium. Equation (1) refers to the first stage in which the price of crude oil, along with the exchange rate, determines the ex-refinery price of Unleaded95 gasoline or diesel. Equation (2) shows the retail price of these two types of fuel as a function of the ex-refinery price. For the two pairs of price series to be linearly cointegrated, the estimated error-term should be stationary. However, to incorporate asymmetric adjustment dynamics, the deviation from the equilibrium u_t is modeled as a threshold autoregressive process, as follows:

$$\Delta u_t = \rho_1 I_t u_{t-1} + \rho_2 (1 - I_t) u_{t-1} + \sum_{i=1}^{n} \varphi_i \Delta u_{t-i} + \omega_t \qquad (3)$$

where I_t is a Heaviside indicator function which depends on the lagged values of the error term in equation (1) according to the specification:

$$I_t = 1 \text{ if } u_{t-1} \geq \tau, 0 \text{ otherwise} \qquad (4)$$

$$I_t = 1 \text{ if } \Delta u_{t-1} \geq \tau, 0 \text{ otherwise} \qquad (5)$$

Similar equations to (3)-(5) above apply for the error term ε_t of equation (2). In equations (3)-(5) above, n denotes the lag length; ρ_1, ρ_2 and φ_i are coefficients and τ is the estimated threshold. The values of ρ_1 and ρ_2 signify the rate at which positive and negative deviations or shocks are adjusted, respectively. The expression $u_{t-1} \geq \tau$ or $\Delta ut_{-1} \geq \tau$ represents positive gaps or deviations equal or above the threshold whereas $u_{t-1} \leq \tau$ or $\Delta u_{t-1} \leq \tau$ captures negative deviations from the estimated threshold. A positive deviation therefore implies a reduction in crude oil price, while a negative deviation signifies an increase in crude oil price. In other words, a positive gap implies a higher ex-refinery price above its equilibrium level, while a negative disequilibrium epitomizes a smaller ex-refinery price compared to its equilibrium. An analogous interpretation applies also to the second stage of distribution between ex-refinery and retail price. Equation (2) is augmented with the lag difference of the residual to control serially correlated errors and the optimal lag length is selected using the Akaike Information Criterion (AIC). Following Enders and Siklos (2001), the model including equations (1-3) and (4) is termed "Threshold Autoregressive model" (TAR) and the model including equations (1-3) and (5) is called "Momentum Threshold Autoregressive model" (MTAR). As indicated by Enders and Granger (1998) and Enders and Siklos (2001), the TAR model captures possible "asymmetric deep movements" while the MTAR accounts for "steep variations" in the series. For example, if the autoregressive decay within the TAR model is large when the retail price is above its equilibrium, negative deviations below the threshold will exhibit more persistence. However, the MTAR model allows differential amounts of autoregressive decay contingent on whether the ex-refinery or retail price is increasing or decreasing. Thus, the MTAR model not only captures spiky asymmetric movements in the price series, but also captures the transmission mechanism if the adjustment of fuel prices at the pump to ex-refinery price changes (or the adjustment of ex-refinery price to crude oil price changes) exhibits more "momentum" in one direction relative to the other.

A formal test for threshold cointegration within both the TAR and MTAR specifications includes the following hypotheses:

Null hypothesis H_0: $\rho_1=\rho_2=0$ (No cointegration), against
Alternative hypothesis H_1: $\rho_1\neq0$ and/or $\rho_2\neq0$ (TAR/MTAR cointegration adjustment process)

The F-statistic (Phi) is compared with the appropriate simulated critical values since the test statistic does not follow a standard distribution.

As an alternative to the case where the threshold value is specified as zero, Chan (1993) proposed a grid search approach which facilitates a consistent estimation of the threshold. This involves arranging the threshold variable i.e. the series of ξ_{t-1} or $\Delta\xi_{t-1}$ for the respective TAR and MTAR models in an ascending order and excluding the highest and lowest 15% of the values. Since the threshold value τ is expected to fall within this range, the search for the consistent estimate of the threshold is conducted by using each of the inner 70% values to estimate the TAR or MTAR model in Eq. (3). The threshold value in the trial that yields the lowest residual sum of squares is then considered as the consistent threshold.

5.2. Asymmetric error-correction model (ECM)

Once we establish evidence for nonlinear cointegration, we estimate an error-correction model (ECM) on the basis of the Granger representation theorem (Engle and Granger, 1987). However, given the evidence for nonlinear cointegration, we estimate an asymmetric ECM (Granger and Lee, 1989) where the error-correction term and the first differences of the price variables are separated into negative and positive variables. The second extension incorporates threshold effects where the error correction term is not just segregated into positive and negative components, but the decomposition is based on deviations from a threshold or equilibrium (Balke and Fomby, 1997; Enders and Granger, 1998). These extensions allow a detailed examination of the asymmetric effects of upstream price changes on the dynamic adjustment of downstream prices. In this study, we specify the following asymmetric ECM:

$$\Delta P_t^{ref} = c_1 + \delta^+ E_{t-1}^+ + \delta^- E_{t-1}^- + \sum_{i=0}^{p} a_i^+ \Delta P_{t-i}^{brent+} + \sum_{i=0}^{p} a_i^- \Delta P_{t-i}^{brent-} + \sum_{i=0}^{p} b_i^+ \Delta ER_{t-i}^+ + \sum_{i=0}^{p} b_i^- \Delta ER_{t-i}^+ + \sum_{i=1}^{p} k_i^+ \Delta P_{t-i}^{ref+} + \sum_{i=1}^{p} k_i^- \Delta P_{t-i}^{ref-} + v_t \quad (6)$$

$$\Delta P_t^{retail} = c_2 + \gamma^+ E_{t-1}^+ + \gamma^- E_{t-1}^- + \sum_{i=0}^{p} g_i^+ \Delta P_{t-i}^{ref+} + \sum_{i=0}^{p} g_i^- \Delta P_{t-i}^{ref-} + \sum_{i=1}^{p} d_i^+ \Delta P_{t-i}^{retail+} + \sum_{i=1}^{p} d_i^- \Delta P_{t-i}^{retail-} + z_t \quad (7)$$

where ΔP^{ref} and ΔP^{Brent} are the refinery and crude oil prices in first difference and ΔER denotes the exchange rate in first difference, segregated into positive ($\Delta P_t^+ = P_t - P_{t-1} > 0$) and negative ($\Delta P_t^- = P_t - P_{t-1} < 0$) variables, respectively. v_t, z_t represent the error terms where the subscript t denotes time and i represents lags. The coefficients δ^+, δ^- and γ^+, γ^- determine the long-run adjustments of refinery and retail prices, respectively. Equivalently, these ECM coefficients are associated with the price adjustment to the long-run equilibrium level. The coefficients a^+, a^-, and b^+, b^- denote the short-run adjustment of refinery price to crude oil price and exchange rate changes, respectively. In a similar manner, g^+, g^- denote the short-run adjustment of retail price to refinery price changes. The error-correction term E_{t-1} appearing in equation (6) is defined as $E^+_{t-1} = I_t u_{t-1}$ (where I_t is contingent on whether $u_{t-1} \geq \tau$ or $\Delta u_{t-1} \geq \tau$) and $E^-_{t-1} = I_t u_{t-1}$ (where I_t hinges on whether $u_{t-1} < \tau$ or $\Delta u_{t-1} < \tau$) and is taken from equation (1). A similar definition applies for the error-correction term of equation (7). As in the cointegration tests, we estimate two types of ECMs which correspond to the TAR and MTAR models and capture different asymmetric adjustments based on the definition of the Heaviside indicator I_t in equations (4) and (5). Since there is no presumption as to which model is more appropriate, the choice of the appropriate adjustment mechanism (TAR or MTAR) is determined by selecting the model with the smallest Akaike Information Criterion (AIC) or Bayesian Information Criterion (BIC) values. Moreover, we use the AIC and BIC to select the maximum lag (p) of the explanatory variables to avoid serially correlated residuals. The specification in equations (6) and (7) permits us to distinguish between long-run and short-run adjustments and perform a formal test of the asymmetric adjustment hypothesis. The test for long-run symmetric adjustment involves the following two null hypotheses in equations (6) and (7), respectively.

Null hypothesis H_{01}: $\delta^+ = \delta^-$: Symmetric adjustment
Alternative hypothesis H_{11}: $\delta^+ \neq \delta^-$: Equilibrium asymmetry in price adjustment.

Null hypothesis H_{01}: $\gamma^+ = \gamma^-$: Symmetric adjustment
Alternative hypothesis H_{11}: $\gamma^+ \neq \gamma^-$: Equilibrium asymmetry in price adjustment.

The Granger causality F-test is also performed in equations (6) and (7) for the following hypotheses:

Null Hypothesis H_{02}: $a_i^+ = a_i^- = 0$,
Alternative Hypothesis: H_{12}: $a_i^+ \neq 0$ and/or $a_i^- \neq 0$, $i=0,\ldots, p$
A rejection of H_{02} implies that Brent price changes Granger cause the ex-refinery price.

Null Hypothesis H_{03}: $b_i^+ = b_i^- = 0$,
Alternative Hypothesis: H_{13}: $b_i^+ \neq 0$ and/or $b_i^- \neq 0$, $i=0,\ldots, p$
A rejection of H_{03} implies that exchange rate changes Granger cause the ex-refinery price.

Null Hypothesis H_{04}: $g_i^+ = g_i^- = 0$

Alternative Hypothesis H_{14}: $g_i^+ \neq 0$ and/or $g_i^- \neq 0$, i=0,…, p

A rejection of H_{04} implies that ex-refinery price changes Granger cause the retail price.

6. Data and Results

6.1 Data

The price transmission dynamics of crude oil to refinery and distribution stage are examined with a daily dataset covering the period from 1/1/2012 until 9/11/2018. The price of Brent crude, which serves as a benchmark price for purchases of oil worldwide, has been obtained from the database of the Research division of the Federal Reserve Bank of St. Louis (FRED) and the exchange rate (defined as number of US dollars per one euro) from the database of the European Central Bank (ECB). The ex-refinery and retail prices of diesel and unleaded95 have been officially requested from the Price Observatory of the Secretariat-General for Trade and Consumer Protection of the Greek Ministry of Economy and Development. Accordingly, the price of Brent crude, measured in US dollars per barrel, is converted into US dollars per liter to be in the same metric units with the other time series. Lastly, all prices do not include taxes and are log-transformed. Series in Figures 1 and 2 depict diesel and unleaded 95 prices, respectively. Descriptive statistics for the Greek oil products are reported in Table 1. These descriptive statistics show that the means of the unleaded95 ex-refinery and retail price are lower than the diesel ex-refinery and retail price respectively, although gasoline prices at the pump in Greece are generally higher compared to diesel prices. Additionally, based on the standard deviation values reported in Table 1, diesel prices in both the refinery and distribution stages are more volatile than the corresponding ones for unleaded95.

The estimation period covers a somewhat volatile time of significant oil price decreases especially during the period 2014–2016. Starting in June 2014, the nominal price of Brent crude oil fell sharply from $112 in June to $62 in December, yielding to a 6-month drop of 44%. The downward trend persisted in 2015 and 2016, ending up in the decade's low of 26$ per barrel in January 2016, that accounts for an aggregate decrease of more than 75%. Assessing the root causes for this decline, which can only be compared to the one during the financial crisis of 2018, Arezki and Blanchard (2014) advocate, primarily, in favor of supply-side factors that generated this decline. More specifically, they identify the key role of the decision of OPEC in late November 2014 to sustain the existing production level despite the quick recovery of Libyan oil production earlier in September 2014. Finally, the afore mentioned contributed to a drastic transformation of the expectations for the future oil prices that accelerated the decline.

On the other side, Prest (2018) and Baumeister and Kilian (2016) present evidence in favor of the “demand-side” explanation and more specifically the role of the stagnant global economic activity and demand for commodities, including but not limited to oil. Hence, it is crucial to check the cointegration relationships for the existence of structural breaks.

6.2. Unit root tests

Perron (1990) suggests that unit roots and structural change are interconnected, leading standard unit root tests to be biased toward nonrejection of the unit root hypothesis if the data are trend stationary with a structural break. For this purpose, we begin our empirical analysis using the Zivot–Andrews (1992) unit root test that allows for an endogenously-specified break and provides both a test of the unit root null hypothesis and the identification of the break location. We apply the Zivot–Andrews (1992) unit root test to the full sample of the daily time-series (Brent, ex-refinery and retail prices) from 2012 to 2018. The results reported in Table 2 confirm the unit root null hypothesis, as well as, the presence of a structural break during 2014, and more specifically on the last day of September or at the beginning of October 2014, depending on the price definition. Figure 3 includes the Zivot-Andrews breakpoint results for all time-series. The presence of the structural break at this point of time is in line with Caporin et al. (2019) who examine the integration property of the series while allowing for breaks. Using Perron’s (1997) test, they find that, independently of the specification of the test (allowing for break either in both trend and intercept, or solely in the intercept), both WTI and Brent prices are subject to a break “in the last quarter of 2014, between September 2014 and October 2014” (Caporin et al., 2019, p. 24).

The result regarding the structural break, as indicated by the econometric test, agrees with the explanation provided previously on the sharp decline of the oil price in the autumn of 2014 due to a sharp oil production cut. This means that in the long run, the pattern of gasoline and diesel prices in Greece does not remain unchanged during the estimated period. As a consequence of the evidence for a break point, we divide our sample into 2 subsamples for the 2 sub-periods before and after the structural break and we perform the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) stationarity test to each price series for both periods. Accordingly, in Table 3 we present the descriptive statistics for each series net of taxes for the two sub-samples and the KPSS results. The latter indicate that the stationarity null hypothesis is rejected for all series at standard significance levels at their levels, but not at first differences (with the exception of Brent and diesel retail where the null is rejected for the differenced series too). We therefore apply the ADF and Phillips-Perron tests for these two series (results available upon request) and conclude that they are both stationary in first differences. Hence, our conclusion is that all series are I(1).

6.3. Nonlinear Cointegration results

Table 4 summarizes the nonlinear cointegration test results of the different price pairs, assuming TAR and MTAR adjustments as specified in Equation (3). We report the values of the threshold τ, the adjustment parameters ρ_1 and ρ_2 with their significance level, the F-statistics of the no-cointegration null hypothesis, and the simulated 5% critical values. All the F-statistics for the 1/2012-9/2014 daily prices exceed the respective 5% critical values for both diesel and unleaded95 for Stage 1 and Stage 2. Consequently, we reject the no-cointegration null hypothesis and find evidence for cointegration with asymmetric processes. For Period 2, we also find similar evidence for both diesel and unleaded95 in Stage 1 and Stage 2[5].

6.4. Error-correction model results

The results of the estimation of TAR or MTAR asymmetric error correction models are presented and discussed in Tables 5-12. The reported asymmetric ECMs refer to the types of fuel (unleaded95 or diesel), the two periods, and the two stages (refining or distribution). We report the long-run and short-run coefficients, some diagnostics, and the p-values of the symmetric adjustment hypothesis and Granger causality tests.

6.4.1. Daily diesel and gasoline prices for "Period 1"

We first report results for the period 2012 – 2014 ("Period 1") for both stages of refining and distribution. Our results refer to the asymmetric error-correction model that is selected by the AIC. Table 5 reports the asymmetric ECM for "Stage 1", i.e., the adjustment of ex-refinery diesel price to crude oil price and exchange rate changes. The equilibrium symmetric adjustment hypothesis (H_{01}) is marginally rejected at the 5% significance level (p-value=0.057). Hence, refinery diesel prices react differently to deviations below or above the equilibrium level. The long-run adjustment coefficients imply that about 5.4% of a negative disequilibrium

[5] Note that the second-period sample starts in early October due to sample adjustment arising from the cointegration test.

due to an increase in crude oil price and/or in exchange rate decays within a day. Thus, a positive disequilibrium is considerably more persistent given the excessively small –in absolute terms- and statistically insignificant value of the positive deviations. The H_{02} null hypothesis is strongly rejected implying that crude oil prices Granger-cause ex-refinery prices. We also find evidence that the exchange rate Granger causes the ex-refinery price, i.e., the H_{03} null is rejected at 1%.

The estimation results for the second stage of price transmission (distribution stage) of diesel are presented in Table 6. In this case, the MTAR model has been selected based on the minimum value of the AIC. We observe that refinery product prices Granger cause retail diesel prices. The p-value (0.490) of the equilibrium symmetric adjustment hypothesis test suggests nonrejection of symmetric price adjustment. Although the positive long-run adjustment parameter (-0.097) is smaller in absolute terms than the negative one (-0.109), and both parameters are statistically significant, symmetric adjustment implies that prices revert to equilibrium with the same pace. On the other hand, the rejection of H_{02} hypothesis (p-value = 0.000) implies short-run adjustment of retail prices to ex-refinery prices.

Table 7 presents the estimation results of the MTAR asymmetric ECM for the pass-through of crude oil price and exchange rate to the ex-refinery price of unleaded95 gasoline. According to the AIC, the MTAR specification is superior to the corresponding TAR. Despite the difference in the magnitude of the long-run adjustment coefficients that refer to the positive and negative deviations from equilibrium, the H_{01} hypothesis which accounts for symmetric adjustment to the long-run equilibrium cannot be rejected based on the large p-value (0.184). Therefore, the reversion to the long-run equilibrium price is symmetric for positive and negative gaps of ex-refinery price of Unleaded95 gasoline. The strong rejection of the H_{02} and H_{03} hypotheses (both p-values are 0.000) suggest that both crude oil price changes and exchange rate changes Granger cause ex-refinery prices.

Table 8 reports the estimated MTAR error-correction model which captures the dynamic relationship between changes in retail Unleaded95 gasoline prices and refinery prices. The results indicate that only positive deviations equal or above the threshold ($u_t \geq -0.002$), caused by decreases in refinery diesel price, are statistically significant at the 1% level and are absorbed at a rate of 4.1% per day. On the other hand, the value for the negative adjustment parameter is statistically insignificant suggesting price rigidity. Considering that the H_{01} null hypothesis of symmetric adjustment is rejected at the 1% significance level, our estimates suggest that Unleaded95 gasoline retail prices are adjusted faster to decreases in refinery price.

6.4.2. Daily gasoline and diesel prices for "Period 2"

For the period 2014–2018, the TAR specification has been selected against the MTAR to better capture the potential asymmetries for diesel in the "Stage 1" phase of refining. The estimated long-run adjustment parameters are presented in Table 9 and indicate that the long-run coefficient for negative deviations is greater in absolute terms than the counterpart for positive deviations. The symmetric adjustment null hypothesis is strongly rejected (p-value=0.000) in favor of the asymmetric adjustment. The adjustment coefficients imply that 6.2% of a unit negative deviation from the equilibrium ($u_t \geq -0.006$), caused by an increase in the price of crude oil and/or in the euro-dollar exchange rate, decays every day, while a 1% decrease in crude oil price and/or in the euro-dollar exchange rate, generating a positive deviation from the equilibrium, is absorbed at a rate of 2% per day. Thus, refinery diesel prices for the period 2014–2018 seem to adjust remarkably faster, roughly three times more swiftly, to negative disequilibrium compared to positive gaps from the equilibrium. The rejection of H_{02} and H_{03} implies that Brent price differences and exchange rate changes Granger cause ex-refinery diesel prices.

In contrast, regarding the second stage of the distribution of diesel and the pass-through from ex-refinery to the retail prices (Table 10), the p-value of H_{01} (0.536) of the symmetric adjustment hypothesis strongly suggests absence of potential equilibrium asymmetries. Therefore, retail diesel prices behave similarly to both deviations, i.e., below or above the equilibrium point.

In the case of Unleaded95 gasoline (Table 11), the MTAR model has been chosen to examine the adjustment dynamics of the ex-refinery price to international crude oil and exchange rate changes. The symmetric adjustment hypothesis H_{01} is strongly rejected (p-value=0.018) implying an asymmetric adjustment process. Within the MTAR model, only the long-run coefficient for negative deviations is found to be significant at 1%, while the coefficient for positive deviations is not statistically different from zero. The adjustment coefficients imply that about 3.1% of a negative disequilibrium due to an increase in crude oil price decays within a day. Thus, positive disequilibrium is considerably more persistent given the excessively small –in absolute terms- and statistically insignificant coefficient of the positive deviations.

For unleaded95 gasoline we experience the same price pattern as in the pass-through of the diesel prices where asymmetries were identified only in "Stage 1". According to Table 12, the long-run symmetric adjustment hypothesis H_{01} could not be rejected for "Stage 2" (p-value=0.265). Hence, we observe an even reaction of Unleaded95 retail prices to both positive and negative deviations due to changes in the refinery gasoline prices.

Our results for "Period 2" are in line with the study of Bragoudakis et al. (2019). They examine the mark-up of both refineries and retailers with daily data and conclude that the refining stage is a source of asymmetries for both Unleaded95 gasoline and diesel while the domestic retail market seems to be competitive with lack of asymmetries in price adjustment. They also claim that weekly or monthly data could result in misleading findings and hide potential asymmetries.

7. Conclusions and policy implications

Drawing from the motivation arising from Peltzman (2000), this paper has re-investigated the phenomenon of asymmetric price pass-through of crude oil prices and exchange rate to the ex-refinery prices and finally to the retail gasoline and diesel prices. During periods of volatile international markets, as the period examined in the present study, this is a high-profile issue, since the lion's share of public drives a car and additionally the transportations sector, which is oil-dependent, accounts for a substantial part of economic activity. Therefore, the phenomenon of energy price asymmetries, being high in the research priorities among energy economists, has been widely examined both theoretically and empirically, especially focusing on the hypothesis that prices rise faster than they fall. Asymmetric price adjustment in the liquid fuel market is often construed as abuse of market power given that varying degrees of price rigidity characterize monopolistic and oligopolistic markets. Our empirical evidence points out to widespread differences with respect to the speed of adjustment and asymmetries in the fuel market in Greece.

Focusing on the first period of our split sample (2012–2014), the results from the daily national level prices lead to the conclusion that diesel retail pricing appears to be competitive, while in the refining stage we observe negative equilibrium asymmetries (ex-refinery diesel price reverts faster to equilibrium to input cost increases than decreases). Regarding the case of unleaded95 gasoline, the results indicate symmetric pass-through of the price in the refining stage, and positive asymmetry in the downstream phase. Thus, the widespread public opinion that fuel prices adjust more swiftly to increasing than decreasing input prices is not supported by the empirical evidence for the case of unleaded95 gasoline, but it can be confirmed for the refining stage of diesel.

On the other hand, examining the results from the second period of our sample that covers the volatile period of 2014 to 2018, we reach out to more unambiguous and straightforward conclusions about the nature and the source of price asymmetries in the country. For both diesel and unleaded95 gasoline, we observe negative price asymmetries in the first stage of the refinery process. More specifically, the ex-refinery price is adjusted more swiftly to negative gaps from the equilibrium due to increases in the crude oil and/or exchange rate comparing to the positive ones. On the contrary, the results for “Stage 2” of distribution indicate that regulatory mechanisms and the market structure are functioning effectively in controlling for potential asymmetries. Thus, for this period the source of asymmetry can be identified in the upstream phase of the transmission process for both liquid fuels.

It is important to underline that defining the root cause for the observed asymmetries or symmetry is beyond the scope of this paper. This is primarily because the empirical models used to capture asymmetric price patterns do not allow explicit modeling and differentiation for different potential causes. However, our results about symmetry in the distribution stage and negative asymmetries in the refinery stage, particularly in the most recent sub-period may be attributed to an increasing search intensity and decreasing search cost for consumers. According to Cabral and Fishman (2012), considering the differences in signals that price variations convey, input cost increases that lead to retail price increases tend to cause a sudden increase in search intensity as well as smaller retail margins and price dispersion. Moreover, contemporary price monitoring and transparency institutions have contributed to significant reduction to consumer search cost mainly though mobile applications and websites that enable consumers to compare retail prices. This ultimately results into the strengthening of the competition among retailers. At this point, it is worth mentioning that the Ministry of Development, Competitiveness, Infrastructure, Transport and Networks contributed crucially towards a transparent and frequent price reporting within its website (www.fuelprices.gr). We hope that further research based on the above conclusions could investigate and provide insights on the factors that deprive refineries from pricing symmetrically, as well as, policy proposals for the competitive function of this market. Moreover, further research could examine the sensitivity of the results to alternative methodological approaches such as asymmetric ARDL cointegration or panel data procedures.

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