Oil and pump prices: Testing their asymmetric relationship in a robust way

Zacharias Bragoudakis[1], Stavros Degiannakis[1,2], George Filis[3*]

[1]Bank of Greece, Economic Research Department, 21 E. Venizelos Avenue, GR10250, Athens, Greece.

[2]Department of Economics and Regional Development, Panteion University of Social and Political Sciences, 136 Syggrou Avenue, 17671, Greece.

[3]Department of Accounting, Finance and Economics, Bournemouth University, 89 Holdenhurst Road, Executive Business Centre, BH8 8EB, Bournemouth, UK.

*Corresponding author's email: gfilis@bournemouth.ac.uk

Abstract:

The aim of this study is to provide a novel method to assess whether retail fuel prices respond asymmetrically to changes in the international crude oil prices. To do so, we consider the whole supply chain, we use daily data and we depart from the current practice in the literature that focuses on prices. Rather, we consider the mark-ups of both the refineries and retailers. Hence, we show that we first need to assess whether the refineries' mark-up responds asymmetrically to the international crude oil prices and subsequently whether the retailers' mark-up shows an asymmetric behaviour relatively to changes in the refined fuel prices. Focusing in Greece as our case study, our findings show that Greek fuel retailers do not change their mark-up behaviour based on changes of the refined fuel price. By contrast, the asymmetric behaviour is evident in the refineries' mark-up relatively to changes in the international crude oil prices, which is then passed through to the retailers and consumers. Finally, we provide evidence that weekly and monthly data mask any such asymmetric relationship. Thus, we maintain that unless the appropriate data frequency, fuel price transformations and the whole supply chain are considered, misleading findings could be revealed.

Keywords: Oil price shocks, fuel prices, asymmetric responses, rockets and feathers, pass-through.

JEL codes: C22, C32, D40, Q41.

1. Introduction

International crude oil prices have experienced huge swings since 2007, when they fluctuated from about $60 per barrel to a record high of $145 in 2008 and subsequently dropped sharply at about $30 in late 2008, or even during the period 2014-2015, when oil lost about 75% of its price. Recently, during 2016 to 2019, oil prices experienced another period of abrupt change rising from about $30 (January 2016) to $78 (September 2018), then dropping back to the levels of $50 in December 2018 before they bounce back to almost $70 in April 2019.

Furthermore, over the last decade or so we have observed the increased financialisation of the oil market, which, in many cases, has resulted in abrupt changes in oil prices (Buyuksahin and Robe, 2014; Le Pen and Sévi, 2017). Such developments certainly affect the pricing strategies of oil companies in both the upstream and downstream sector. Although it primarily affects the former sector given their large fixed costs, similar observations have been extensively reported for the downstream sector, as well.

Indeed, there is a wealth of literature that assesses the effects of crude oil price fluctuations on the pump price and whether the response of the latter is asymmetric towards increases and decreases of the former (some recent studies include Valadkhani *et al*., 2015; Rahman, 2016; Apergis and Vouzavalis, 2018; Eleftheriou *et al*. 2018; Kang *et al*., 2018). This asymmetric behaviour has been characterised by a term coined by Bacon (1991) called *rockets and feathers*. The *rockets and feathers* phenomenon suggests that when crude oil prices increase then there is an immediate increase in pump fuel prices; whereas during crude oil prices decreases, pump prices tend to adjust at a much slower pace. Perdiguero-García (2013), Kristoufek and Lunackova (2015) and more recently Cook and Fosten (2018) provide an extensive review of this line of research. On the whole, the existing evidence demonstrates several interesting regularities.

First, the reported findings do not reach a consensus since there are studies that find evidence in favour of the asymmetric behaviour (see for instance, Duffy-Deno, 1996; Balke *et al.*, 1998; Grasso and Manera, 2007; Blair *et al.*, 2017), whereas other studies cannot provide any support to such claims (Shin, 1994; Godby *et al.*, 2000; Balaguer and Ripollés, 2012; Karagiannis *et al.*, 2015).

Second, studies concentrate their attention to the effects of oil prices on the pump prices, largely ignoring the effects of the former on the refining industry (see for instance, Manning, 1991; Borenstein *et al.*, 1997; Godby *et al.*, 2000; Meyler, 2009; Rahman, 2016; Apergis and Vouzavalis, 2018). Delpachitra (2002) is one of scarce studies that shows that price adjustments in the domestic market do not respond effectively to changes in the international oil prices. By contrast, they report that domestic wholesale prices are the key to determining retail prices. Thus, the lack of competition in the wholesale market was found to be the main cause of the weak adjustment of retail prices. Galeotti, *et al*. (2003) and Kaufmann and Laskowski (2005) also focus on the refining industry, although they reach to different conclusions. The former study focuses on five European countries (Germany, Spain, France, Italy and the UK) and show that asymmetric behaviour is evident in both the refining and distribution stages. By contrast, Kaufmann and Laskowski (2005) study the US market and they show that the refining margin does not exhibit any asymmetric behaviour towards changes in the crude oil prices. More recently, Balaguer and Ripollés (2012) find evidence in favour of a symmetric behaviour of retail fuel prices to changes in the wholesale prices.

Third, the most common data frequency that is considered by the existing literature is either weekly or monthly (e.g. Kirchgässner and Kübler, 1992; Shin, 1994; Duffy-Deno, 1996; Godby *et al.*, 2000; Bermingham and O'Brien, 2011). Authors have almost ignored the potential effects at daily frequency with some exception to include the studies by Bachmeier and Griffin (2003), Oladunjoye (2008) and recently Gautier and Saout (2015) and Lahiani *et al*. (2017).

Forth, studies in this line of research most commonly employ techniques such as the asymmetric error correction model (or variants of this model), threshold autoregressive and momentum threshold autoregressive (TAR and MTAR) models and panel regressions (see, Manning, 1991; Balke *et al.*, 1998; Bettendorf *et al.*, 2003; Grasso and Manera, 2007; Panagiotidis and Rutledge, 2007; Douglas, 2010; Balaguer and Ripollés, 2016, among others). Table 1 provides a summary of some selected studies.

[TABLE 1 HERE]

It is rather evident from the brief overview of the related literature that there are certain gaps in this line of research, which are considered in this study.

First, we are among the very few studies that concentrate on the whole supply chain from the international crude oil prices to the pump prices so to identify where there might be any asymmetric behaviour.

Second, we consider three different data frequencies (daily, weekly and monthly) in order to assess whether lower frequencies mask any asymmetric behaviour.

More importantly, though, we depart from the current practice in the literature that centres its attention solely on pump prices. Rather, our focus is on both the refineries and retailers, as well as, on their mark-ups rather than on refined fuel and pump prices. We do so since refined fuel and pump prices may not necessarily reveal the pricing strategy of both refineries and retailers. However, the asymmetric behaviour is expected to be impacted by the mark-up that refineries and/or retailers will charge on top of the import cost of oil and purchase price of refined fuel, respectively. For instance, there could be cases where pump prices may not change due to declines in crude oil prices; however, this could be due to changes in taxation, while the mark-up remains constant. Hence, in such case, the identification of the asymmetric behaviour would be inappropriately identified. Thus, it is important to assess first whether the refineries' mark-up responds asymmetrically to the international crude oil prices and subsequently whether the retailers' mark-up shows an asymmetric behaviour relatively to changes in the refineries' fuel prices.

Brown and Yücel (2000) have claimed that the observed asymmetry in the pump prices could be sourced to the changing profit margins (i.e. mark-ups) of retailers, although they did not formally test this claim in the same fashion as we do in the present study.

Against this backdrop, the aim of this paper is to investigate the impact of the international crude oil prices on the oil downstream sector, focusing on both the refining industry, as well as, the retail (petrol stations) sector, using a novel approach. Our case study is the Greek fuel market given the industries characteristics, as well as, due to the fact that we can employ a unique dataset, which is available on a daily basis and it is not publicly available (details can be found in Section 2).

We should highlight that there are scarce studies that focus on the Greek downstream oil sectors. One such study is by Angelopoulou and Gibson (2010) who focus on the different prefectures of the Greek region and do not support the view that pump prices asymmetrically respond to positive and negative changes in the crude oil prices. They further suggest that any observed asymmetry is due to the tax changes. Similar results are also provided by a recent study of Apergis and Vouzavalis (2018), who report a symmetric pass-through of crude oil prices to retail pump prices.

By contrast, Polemis (2012) maintains that the reactions of the retail fuel prices to wholesale price decreases and increases are asymmetric. The findings by Bragoudakis and Sideris (2012), regarding the retail sector, corroborate those of Polemis (2012).

Succinctly put, our findings show that our novel approach allows us to uncover the true relationships (asymmetric or symmetric). In particular, using the whole supply chain and the downstream sector's daily mark-ups, rather than prices, we show that the Greek fuel retailers do not alter their mark-up behaviour based on positive or negative changes of the refined fuel prices (symmetric behaviour). By contrast, the asymmetric behaviour is evident in the refineries' mark-up relatively to positive and negative changes in the crude oil prices, which is then passed through to the retailers and consumers. Worth noting is the evidence that weekly and monthly data do mask the asymmetric relationship along the whole supply chain. Thus, we demonstrate that unless appropriate transformation of the data and the whole supply chain are considered, results may reveal misleading conclusions.

The structure of the remaining paper is as follows. Section 2 presents the data and methods used in this study. Section 3 provides evidence in favour of an asymmetric relationship between crude oil prices and pump prices, while Section 4 re-models the relationship between crude oil and pump prices. Section 5 provides i) a series of robustness tests using weekly and monthly data and ii) develops a framework that accounts for a nonzero threshold parameter in order to distinguish between asymmetric changes in crude oil (and refinery prices). Finally, Section 6 concludes the study.

2. Data and methods

2.1 Data description

As shown in Section 1 and Table 1, previous studies mainly consider weekly or monthly data, employ mainly asymmetric error correction models and focus on crude oil and pump prices. We depart from these standard approaches, considering daily data, employing a short-run model and focusing on the mark-ups of refineries and retailers, rather than on crude oil and fuel prices. We maintain that in order to assess any asymmetric behaviour in fuel prices it should be performed based on the core gross profitability ratio. In this study we use both the retailers' mark-up in pre- and post-tax fuel prices. Furthermore, we maintain that weekly and, more importantly, monthly data may mask any asymmetric relationship, given that such price behaviour should not be expected to hold for lengthy time periods.

For the purpose of the current study, we use *PLATTS* price (as a proxy of import prices given that the cost of imported crude oil (*CIF*) prices were not available at daily frequency)[1], refined fuel prices, final pump prices for the unleaded 95, as well as, the total tax imposed on the fuel prices. The data have been obtained from the Greek Ministry of Economy and Development and the period of study is from the 7th January 2014 until 10th April 2018 (1267 daily observations). The data period is dictated by the data availability of the daily data. Table 2 and Figure 1 present the descriptive statistics of the data and their visual representation, respectively.

[TABLE 2 HERE]

[FIGURE 1 HERE]

From Table 2 it is evident the very high proportion of taxes to the retail fuel price, which, on average, is about 65.5%. Another interesting observation from Table 2 is the fact that the variation in retail prices and retail mark-ups are materially lower compared to the refined fuel prices and refineries mark-up, respectively, as suggested by the coefficient of variation. This is rather interesting, suggesting that the refineries' prices are more volatile, although this is not clearly evident in Figure 1. Furthermore, it is important to note that the dispersion of *PLATTS*, refined fuel and retail prices differ, possibly suggesting that we should not anticipate a constant relationship among them. Figure 1 also confirms the high contribution of taxes in the final retail fuel prices.

2.2 Methods

We shall reiterate that, as shown in Section 1, the bulk literature assesses the (asymmetric) relationship between international crude oil prices and pump prices, using low frequency data (i.e. weekly or monthly). We opine that any asymmetry is not expected to be present in the longer run and thus low frequency data may mask the real relationship. Furthermore, these previous studies use crude oil and pump prices. More importantly, these studies tend to ignore the whole supply chain. This is suggestive of the fact that they make an implicit assumption that crude oil prices directly affect pump prices. We maintain that this may result in misleading findings.

[1] We opt to use the *PLATTS* prices rather than international crude oil prices due to the fact that oil transactions are taking place in the former (see, for instance, Balaguer and Ripollés, 2016).

Thus, in this study we present a novel approach that can reveal the true relationships among international crude oil prices, refined fuel prices and pump prices.

Intentionally, and in order to provide evidence in favour of using the whole supply chain, we first follow the bulk of the literature presented in Section 1, starting our analysis by investigating the existence of asymmetric behaviour of retail prices to changes in international crude oil prices. Subsequently, we demonstrate how the results could differ if we consider the whole supply chain.

2.2.1 Modelling Retailers' mark-up

We denote $\left\{y_t^{(ret)}\right\}_{t=1}^{T}$ and $\left\{y_t^{(ret\_tax)}\right\}_{t=1}^{T}$ the daily retailers' mark-up without and with the effect of taxation, respectively. For $y_t^{(ret\_tax)} = \frac{Rp_t}{R_t+Tf_t+Tv_t}$ and $y_t^{(ret)} = \frac{Rp_t}{R_t}$ where, Rp_t, R_t, Tf_t, and Tv_t, represent the daily retail gross profit, refined fuel prices, fixed taxation and variable taxation, respectively. The $Rp_t = PR_t - (R_t + Tf_t + Tv_t)$, with PR_t denoting the after-tax retail fuel price.

We proceed to the estimation of the most recent days that the retailers' mark-ups may be impacted by the *PLATTS* prices. The retailers order fuel at irregular days depending of the demand from the end users and the prices offered in the international crude oil market. Hence, we estimate the average *PLATTS* price of the *K* most recent days that maximize the coefficient of determination for the relation between the deviations of the refined fuel prices and retailers' mark-up. Hence, we seek to estimate the following regression:

$$y_t^{(ret\_tax)} = a_0 + a_1 I_{\{\bar{P}_t > \bar{P}_{t-1}\}} + u_t, \tag{1}$$

maximizing the following expression:

$$\max_K \left(1 - \frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret\_tax)} - \bar{y}^{(ret\_tax)}\right)^2} \right), \tag{2}$$

where $\bar{y}^{(ret\_tax)}$ denotes the average retailers' mark-up including the taxation effect on the final fuel price. The $I_{\{\bar{P}_t > \bar{P}_{t-1}\}}$ denotes an indicator variable of the form:

$$I_{\{\bar{P}_t > \bar{P}_{t-1}\}} = \begin{cases} 0 & \text{if} \quad K^{-1}\sum_{k=1}^{K}(P_{t-k}) > K^{-1}\sum_{k=1}^{K}(P_{t-1-k}) \\ 1 & \text{if} \quad K^{-1}\sum_{k=1}^{K}(P_{t-k}) \leq K^{-1}\sum_{k=1}^{K}(P_{t-1-k}) \end{cases}, \tag{3}$$

with P_t being the *PLATTS* prices, $\bar{P}_t = K^{-1}\sum_{k=1}^{K}(P_{t-k})$ being the average *PLATTS* prices over *K* days and *k*>0[2].

Naturally, we proceed with a numerical solution of the $\max_K(.)$, as an explicit closed form solution is not possible. The optimum number of the most recent days is $K = 17$ for $\max_K(.) = 32.5\%$ (see Figure 2).

[FIGURE 2 HERE]

Hence, we infer that overall retailers are affected by international crude oil prices, and subsequently form their mark-up, over the seventeen previous days. Based on the above, the estimated model is:

$$y_t^{(ret\_tax)} = \gamma_0 + \gamma_1 I_{\{\bar{P}_t > \bar{P}_{t-1}\}t} + \gamma_2\left(17^{-1}\sum_{k=1}^{17}(P_{t-k}) - 17^{-1}\sum_{k=1}^{17}(P_{t-1-k})\right) + \gamma_3 I_{\{\bar{P}_t > \bar{P}_{t-1}\}t}\left(17^{-1}\sum_{k=1}^{17}(P_{t-k}) - 17^{-1}\sum_{k=1}^{17}(P_{t-1-k})\right) + \varepsilon_t, \quad (4)$$

where we allow both the intercept and slope to differ between increases and decreases of $\bar{P}$, and $I_{\{\bar{P}_t > \bar{P}_{t-1}\}} = \begin{cases} 0 & \text{if} \quad \bar{P}_t > \bar{P}_{t-1} \\ 1 & \text{if} \quad \bar{P}_t \leq \bar{P}_{t-1} \end{cases}$ presents the indicator variable, for $K = 17$.

Coefficient γ_0 shows the effects of the average *PLATTS* prices on retailers' mark-up and γ_2 indicates the effect of the difference in the average *PLATTS* prices between time t and $t-1$. Equivalently, $\gamma_0 + \gamma_1$ show the effect of decreasing average *PLATTS* prices, whereas $\gamma_2 + \gamma_3$ denote the effects of decreasing average PLATTS prices at time t relatively to time $t-1$.

Given our interest to assess also the effect of taxation on the abovementioned relationship, we further estimate the following regression:

$$y_t^{(ret)} = a_0 + a_1 I_{\{\bar{P}_t > \bar{P}_{t-1}\}} + u_t, \quad (5)$$

for $\max_K\left(1 - \frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret)} - \bar{y}^{(ret)}\right)^2}\right)$,where, $\bar{y}^{(ret)}$ denotes the average retailers' mark-up on the pre-tax fuel prices and $I_{\{\bar{P}_t > \bar{P}_{t-1}\}}$ presents the indicator variable, as previously.

3. (A)symmetric behaviour of retailers to oil price changes

The results for the retailers' mark-up, excluding and including the effect of taxation, are presented in Tables 3 and 4.

[TABLES 3 and 4 HERE]

[2] We do not consider *k*=0 since in such case both the right- and left-hand side variables would be simultaneously determined.

Both tables provide the same findings, i.e. that retailers seem to follow a different pricing strategy depending on whether the 17-days moving average *PLATTS* prices are increasing or decreasing. In particular, irrespectively of the effect of taxation, the indicator variable is highly significant in both the constant and the slope. The positive and significant values of γ_1 coefficients suggest that when the average *PLATTS* prices are decreasing, the average retail fuel prices are higher (i.e. $\gamma_0 < \gamma_0 + \gamma_1$).[3]

Turning our attention to the slope, we observe that coefficient γ_2 is negative and statistically significant, whereas γ_3 is not significant. This is suggestive of the fact that retailers' mark-up does not change when the moving average of *PLATTS* prices at time t, relative to their moving average at time $t-1$, are higher.

Overall, these results clearly suggest that there is an asymmetric behaviour in the pricing strategy of retailers; where during low *PLATTS* price levels they tend to increase their mark-up significantly more compared to the higher *PLATTS* price levels. Even more, we observe that the exclusion of taxation does not alter our findings. Our results could suggest that they corroborate those of the existing literature, as discussed in Section 1.

More specifically, the results provide evidence in favour of the *rockets and feathers* hypothesis, whereby fuel prices tend to decline at a slower pace when international crude oil prices drop compared to their increase rate when oil prices increase. As Brown and Yucel (2000) suggest, there are various reasons why such asymmetry may exist, including, market concentration and market power in the retail fuel industry, consumers' reactions to changes in fuel prices or inventory management, among others. We note that it falls beyond the scope of the present study to assess which are the most important factors that apply to our case study of the Greek market. In any case, irrespectively of the drivers of asymmetry, our findings show that there is a loss in consumer welfare as a result of such retail price behaviour to decreases in international crude oil prices.

[3] We consider coefficient covariance estimators that are robust to the presence of heteroscedasticity, employing the method proposed by MacKinnon and White (1985) based on the seminal work of White (1980).

4. Re-modelling the relationship between crude oil and pump prices

4.1. Retailers' mark-up

Section 3 provides evidence in favour of an asymmetric relationship between international crude oil prices (*PLATTS*) and pump prices. However, we need to make an important observation here. Retailers do not buy their fuel directly from the international crude oil market. Rather, they purchase their fuel from the refineries, hence the behaviour of their mark-up is more appropriately to be assessed based on the fluctuations of the refineries' fuel prices rather than the *PLATTS* prices.

So next, we re-estimate our models from Section 3 based on the retailers' mark-up, as a percentage of the refined fuel prices (R_t). Based on the above, the estimated model, including the effect taxation is:

$$y_t^{(ret\_tax)} = \gamma_0 + \gamma_1 I_{\{\overline{RT}_t > \overline{RT}_{t-1}\}t} + \gamma_2 (14^{-1} \sum_{k=1}^{14} (R_{t-k} + Tf_{t-k} + Tv_{t-k}) - 14^{-1} \sum_{k=1}^{14} (R_{t-1-k} + Tf_{t-1-k} + Tv_{t-1-k})) + \gamma_3 I_{\{\overline{RT}_t > \overline{RT}_{t-1}\}t} (14^{-1} \sum_{k=1}^{14} (R_{t-k} + Tf_{t-k} + Tv_{t-k}) - 14^{-1} \sum_{k=1}^{14} (R_{t-1-k} + Tf_{t-1-k} + Tv_{t-1-k})) + \varepsilon_t, \quad (6)$$

where, $RT_t = R_t + Tf_t + Tv_t$ is the refined fuel prices along with the taxes and $\overline{RT}_t = K^{-1} \sum_{k=1}^{K} (RT_{t-k})$. The R_t is the refined fuel price and $\bar{R}$ is the average refined fuel prices. The $I_{\{\overline{RT}_t > \overline{RT}_{t-1}\}} = \begin{cases} 0 & \text{if} \quad \overline{RT}_t > \overline{RT}_{t-1} \\ 1 & \text{if} \quad \overline{RT}_t \leq \overline{RT}_{t-1} \end{cases}$ presents the indicator variable, for $K = 14$, as shown in Figure 3.

[FIGURE 3 HERE]

The estimated model, without the taxation effect, is:

$$y_t^{(ret)} = \delta_0 + \delta_1 I_{\{\bar{R}_t > \bar{R}_{t-1}\}t} + \delta_2 (14^{-1} \sum_{k=1}^{14} (R_{t-k}) - 14^{-1} \sum_{k=1}^{14} (R_{t-1-k})) + \delta_3 I_{\{\bar{R}_t > \bar{R}_{t-1}\}t} (14^{-1} \sum_{k=1}^{14} (R_{t-k}) - 14^{-1} \sum_{k=1}^{14} (R_{t-1-k})) + \varepsilon_t, \quad (7)$$

where $I_{\{\bar{R}_t > \bar{R}_{t-1}\}} = \begin{cases} 0 & \text{if} \quad \bar{R}_t > \bar{R}_{t-1} \\ 1 & \text{if} \quad \bar{R}_t \leq \bar{R}_{t-1} \end{cases}$, for $K = 14$. The results are shown in Tables 5 and 6.

[TABLE 5 and 6 HERE]

It is rather interesting that when we generate estimates based on the appropriate fuel prices (i.e. refined fuel prices rather than international crude oil prices - *PLATTS*), the retailers' asymmetric behaviour disappears, regardless the incorporate or exclusion of the taxation effect. This is evident by the insignificant coefficients γ_1 and γ_3 on Table 5 and δ_1 and δ_3 on Table 6. This is an important finding, as we convincingly show that unless the appropriate prices are considered in this line of enquiry, we may reveal misleading findings.

A reasonable question that follows is where the observed asymmetric behaviour, shown in Section 3, may rest, if not within the retail sector. Possibly, this asymmetry is evident at the previous stage of the supply chain. Hence, in the following section we test whether the asymmetric behaviour can be traced to the refineries.

4.2 (A)symmetric behaviour of refineries to oil price changes

To model refineries' behaviour, let us denote as $\left\{y_t^{(ref)}\right\}_{t=1}^{T}$ the daily refineries' mark-up, for $y_t^{(ref)} = \frac{R_t - P_t}{P_t}$, where R_t and P_t denote the daily refined fuel and *PLATTS* prices, respectively.

As in the case of retailers, refineries also buy oil at irregular days depending on the required amount and the offered prices. Hence, we estimate the average *PLATTS* price of the K most recent days that maximize the coefficient of determination for the relationship between the deviations of the *PLATTS* prices and refineries' mark-up. Hence, we seek to maximise the following expression:

$$\max_{K}\left(1 - \frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ref)} - \bar{y}^{(ref)}\right)^2}\right), \tag{8}$$

for the regression:

$$y_t^{(ref)} = a_0 + a_1 I_{\{\bar{P}_t > \bar{P}_{t-1}\}} + u_t, \tag{9}$$

where $I_{\{\bar{P}_t > \bar{P}_{t-1}\}}$ is the indicator variable denoted in section 2.2.1 and $\bar{y}^{(ref)}$ is the average refineries' mark-up.

The optimum number of the most recent days is $K = 3$, for $\max_{K}(.) = 25.1\%$, as it can be seen in Figure 4.

[FIGURE 4 HERE]

Hence, we infer that overall the refineries' purchase prices, and subsequently their mark-ups, are shaping up from the *PLATTS* prices of the three most recent days. Even though the number of days for the moving average calculation are endogenously identified, our finding closely matched with the sentiment of the Hellenic Petroleum Marketing Companies Association. The estimated model is:

$$y_t^{(ref)} = \beta_0 + \beta_1 I_{\{\bar{P}_t > \bar{P}_{t-1}\}} + \beta_2(3^{-1}\sum_{k=1}^{3}(P_{t-k}) - 3^{-1}\sum_{k=1}^{3}(P_{t-1-k})) + \beta_3 I_{\{\bar{P}_t > \bar{P}_{t-1}\}}(3^{-1}\sum_{k=1}^{3}(P_{t-k}) - 3^{-1}\sum_{k=1}^{3}(P_{t-1-k})) + \varepsilon_t, \quad (10)$$

where $I_{\{\bar{P}_t > \bar{P}_{t-1}\}} = \begin{cases} 0 & \text{if} \quad \bar{P}_t > \bar{P}_{t-1} \\ 1 & \text{if} \quad \bar{P}_t \leq \bar{P}_{t-1} \end{cases}$ presents the indicator variable, for $K = 3$.

The results for the refineries are shown in Table 7. The evidence presented from the model of equation 10 is rather clear. Even though the β_1 coefficient is not statistically significant, the β_3 coefficient is highly significant and negative. Thus, we show that when the moving average *PLATTS* at time t relative to their moving average at time $t-1$ are lower during the low *PLATTS* price levels, then the refineries' mark-up tends to increase even faster, compared to the same behaviour during the high *PLATTS* price levels (i.e. $\beta_2 < \beta_2 + \beta_3$, based on the opposite signs).

These results clearly suggest that there is an asymmetric behaviour in the pricing strategy of refineries; where, during decreasing *PLATTS* price levels they tend to increase their mark-up significantly more compared to the increasing *PLATTS* price levels. Such asymmetric behaviour could be the result of market concentration and market power in the refining sector (which could lead to oligopolistic practices) or possibly to the cost structure of the industry. The end result, though, is that such asymmetric behaviour leads to consumer welfare loss when the international oil prices are pushed downwards.

[TABLE 7 HERE]

Figures 5 and 6 corroborate our findings from Table 7. In Figure 5 we depict the symmetric behaviour between the refineries' mark-up and the *PLATTS* price changes. It is evident that there is a negative relationship, yet we cannot clearly distinguish whether this relationship has a different behaviour during decreasing and increasing *PLATTS* price levels. The latter is exhibited in Figure 6. It is rather clear that the slope in the lower panel of Figure 6 (which is the decreasing *PLATTS* price levels) is steeper compared to the slope in the upper panel. Even more, the refineries' mark-up levels are also higher in the lower panel (see y-axes).

[FIGURES 5 and 6 HERE]

5. Robustness tests

For robustness and comparative purpose, we run the same models as in Section 4.2, using weekly and monthly data, which are the most common data sampling frequencies used by the existing studies. The results are shown in Table 8. We have estimated the models for the refineries only, since this is where we have identified the asymmetric behavior. We estimate the model in equation 10 at both weekly and monthly frequencies. For additional robustness, we convert the daily data into weekly and monthly using both the last daily observation of the week or month, as well as, the average daily prices of the week or month.

[TABLE 8 HERE]

The results clearly show that the evidence of asymmetric behavior disappears when we use the data at a lower sampling frequency (all β_1 and β_3 coefficients that are reported on Table 8 are statistically insignificant, with the exception of the β_3 coefficient on the weekly frequency at the lower part of Table 8). Therefore, our findings clearly suggest that using lower sampling frequencies (i.e. lower than daily), which is rather common in the existing literature, is not the adequate approach to identify the possible asymmetries. The asymmetric effect is a short run phenomenon, so the lower frequency analysis masks this. This finding also suggests that modelling frameworks which are directed to test long run equilibrium such as asymmetric error correction or threshold cointegration models should not be used unless the short run relationship is first examined.

So far, we distinguish between positive and negative changes in crude oil or refinery prices so as to assess the asymmetric behaviour of retailer and refineries. However, it is possible that there may also be non-zero threshold parameters. In such case, the potential asymmetric responses will be both sign and size dependent. To assess such possibility, we develop a framework that accounts for a nonzero threshold parameter in order to distinguish between asymmetric changes in crude oil (or refinery prices); i.e. non only symmetric changes around zero. The optimal value of the threshold parameter can be iteratively determined by conducting a grid search and i) either minimizing the sum of the squared residuals ii) or maximizing the likelihood function or any other goodness of fitness function, such as the function that we have utilized in the paper.

So, we proceed to the estimation of the following regression for the identification of the retailers' asymmetric behavior:

$$y_t^{(ret\_tax)} = a_0 + a_1 I_{\{\bar{P}_t - \bar{P}_{t-1} > \omega\}} + u_t, \quad (11)$$

by maximizing the expression:

$$\max_{K,\omega}\left(1-\frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret\_tax)}-\bar{y}^{(ret\_tax)}\right)^2}\right), \tag{12}$$

where $I_{\{\bar{P}_t-\bar{P}_{t-1}>\omega\}}$ denotes an indicator variable of the form:

$$I_{\{\bar{P}_t-\bar{P}_{t-1}>\omega\}}=\begin{cases}0 \quad \text{if} \quad K^{-1}\sum_{k=1}^{K}(P_{t-k})-K^{-1}\sum_{k=1}^{K}(P_{t-1-k})>\omega \\ 1 \quad \text{if} \quad K^{-1}\sum_{k=1}^{K}(P_{t-k})-K^{-1}\sum_{k=1}^{K}(P_{t-1-k})\leq\omega.\end{cases} \tag{13}$$

The $\bar{y}^{(ret\_tax)}$ denotes the average retailers' mark-up including the taxation effect on the final fuel price, P_t are the PLATTS prices, $\bar{P}_t=K^{-1}\sum_{k=1}^{K}(P_{t-k})$ is the average PLATTS prices over K days. The threshold parameter ω is incorporated in order to distinguish between asymmetric changes in PLATTS prices. As an explicit closed form solution for $\max_{K,\omega}(.)$ is not possible, we proceed with its numerical solution conducting a grid search.

The optimum number of the most recent days is $K=25$ and the threshold parameter is $\omega=-0{,}0006$ for $\max_{K,\omega}(.)=33.6\%$. Figure A1, in the appendix, plots the heat map of the grid search for various values of K and ω. Tables A1 and A2, in the appendix, present the estimated models for the retailers' mark-up, excluding and including the effect of taxation.

Both tables provide similar findings with the models presented in Section 3. Hence, when we assume for asymmetric changes in PLATTS prices, the threshold parameter equals to $\omega=-0{,}0006$ providing a $\max_{K,\omega}(.)=33.6\%$, which is very close to $\max_{K}(.)=32.5\%$. So, even when we account for a nonzero threshold parameter, our findings are similar with Tables 3 and 4.

Regarding the models based on the retailers' mark-up, as a percentage of the refined fuel prices (R_t), we proceed to the estimation of the regression:

$$y_t^{(ret\_tax)}=a_0+a_1 I_{\{\overline{RT}_t-\overline{RT}_{t-1}>\omega\}}+u_t, \tag{14}$$

by maximizing the expression:

$$\max_{K,\omega}\left(1-\frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret\_tax)}-\bar{y}^{(ret\_tax)}\right)^2}\right), \tag{15}$$

where $I_{\{\overline{RT}_t-\overline{RT}_{t-1}>\omega\}}$ denotes an indicator variable of the form:

$$I_{\{\overline{RT}_t-\overline{RT}_{t-1}>\omega\}} = \begin{cases} 0 & \text{if} \quad \overline{RT}_t - \overline{RT}_{t-1} > \omega \\ 1 & \text{if} \quad \overline{RT}_t - \overline{RT}_{t-1} \leq \omega. \end{cases} \tag{16}$$

The $RT_t = R_t + Tf_t + Tv_t$ is the refined fuel prices along with the taxes and $\overline{RT}_t = K^{-1}\sum_{k=1}^{K}(RT_{t-k})$. The optimum number of the most recent days is $K = 20$ and the estimated threshold parameter equals to $\omega = -0{,}0002$ for $\max_{K,\omega}(.) = 32.6\%$. Figure A2 plots the heat map of the grid search for various values of K and ω. Tables A3 and A4, in the appendix, present the estimated models for the retailers' mark-up, including and excluding the effect of taxation. Both tables provide similar findings with the models presented in Section 4 (see Tables 5 and 6). Hence, when we assume for asymmetric changes in the refined fuel prices, those asymmetries are almost indistinguishable; the threshold parameter equals to $\omega = -0{,}0002$ almost equal to zero, providing a $\max_{K,\omega}(.) = 32.6\%$, which is very close to $\max_{K}(.) = 31.5\%$.

Finally, we focus on the refineries' asymmetric behavior, seeking to maximise:

$$\max_{K,\omega}\left(1 - \frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ref)} - \bar{y}^{(ref)}\right)^2}\right), \tag{17}$$

for the regression:

$$y_t^{(ref)} = a_0 + a_1 I_{\{\bar{P}_t-\bar{P}_{t-1}>\omega\}} + u_t, \tag{18}$$

where

$$I_{\{\bar{P}_t-\bar{P}_{t-1}>\omega\}} = \begin{cases} 0 & \text{if} \quad K^{-1}\sum_{k=1}^{K}(P_{t-k}) - K^{-1}\sum_{k=1}^{K}(P_{t-1-k}) > \omega \\ 1 & \text{if} \quad K^{-1}\sum_{k=1}^{K}(P_{t-k}) - K^{-1}\sum_{k=1}^{K}(P_{t-1-k}) \leq \omega. \end{cases}$$

The optimum number of the most recent days is $K = 25$ and the estimated threshold parameter equals to $\omega = -0{,}0008$ for $\max_{K,\omega}(.) = 26.5\%$. Figure A3 plots the heat map of the grid search for various values of K, ω. Table A5 presents the estimated models for the refineries' mark-up based on PLATTS prices, which corroborate the findings presented in Table 7. Hence, when we assume for asymmetric changes in PLATTS prices, the threshold parameter equals to $\omega = -0{,}0008$, providing a $\max_{K,\omega}(.) = 26.5\%$, which is very close to $\max_{K}(.) = 25.1\%$.

Once again, even when we account for a nonzero threshold parameter, our findings remain robust.

6. Concluding remarks

The aim of this paper is to assess the potential asymmetric behaviour of pump prices on increasing and decreasing crude oil prices, employing a novel approach. In particular, unlike the bulk of the existing literature, we consider the whole supply chain in order to discover whether and at which stage such asymmetric behaviour may exist. Even more, we depart from the practice of the existing literature that focuses on the actual fuel prices, but rather we focus on the refineries' and retailers' mark-ups based on the premise that any asymmetric behaviour should be evident in the pricing strategy of these two stakeholders. Our case study is the Greek downstream sector due to the availability of the unique dataset.

Overall, our findings based on daily data show that the fuel retailers do not change their mark-up behaviour based on increasing or decreasing refined fuel price. By contrast, refineries' mark-up changes relatively to changes in the crude oil prices, which is suggestive of an asymmetric behaviour that is then passed through to the retailers and consumers.

Systematic asymmetry in price adjustments could have negative consequences for the economy as a whole and a continuing deterioration of consumers' purchasing power to the benefit of producers/suppliers.

It is mentioned that the Greek gasoline market is characterised by high concentration, since there exist two companies in the refining sector, four large companies in the wholesale market (which have a market share of more than 50%) and each of them has a nationwide network of fuel stations. The structure of the oil market in Greece has also been the topic of monitoring and research in a number of reports of the Hellenic Competition Commission (HCC), which repetitively stated the need for further liberalisation of the market (see, for instance, Hellenic Competition Commission, 2012). It has also been subject of policy recommendations by international organizations (such as, OECD, 2017) and by institutions, such as the International Monetary Fund, the European Commission and the European Central Bank (see, for example, Memorandum of Understanding, 2015).

For the Greek gasoline market, it is crucial that the competition authorities monitor the market, in particular the HCC to ensure competitive operation to the greatest possible extent (see also Balaguer and Ripolles, 2012, Polemis and Fotis, 2013 and Asane-Otoo and Schneider, 2015 for similar policy implications). This becomes even more crucial in periods of recession, as the Greek economy dramatically faced over the past decade, when consumers have to deal with a general decline in their income level and living standards. The matter has additional implications in economies with a high concentration of suppliers, who have high market power and could, thus, abuse their dominant position.

The paper provides a robust empirical evidence of an asymmetric behaviour of the refineries' mark-up changes relatively to changes in the crude oil prices for the Greek gasoline market. This evidence of asymmetric behaviour from the side of refiners should be taken into account from the HCC. A systematic monitoring of the market conditions and regulations by the HCC is required, which should focus on the practices of the refineries' companies in order to ensure price transparency and prevent, if any, oligopolistic practices.

We further highlight that the use of weekly and monthly data mask this asymmetric relationship. Also, we convincingly show that unless the appropriate fuel price transformation is considered (i.e. mark-ups), we may reveal misleading findings. Thus, our results certainly provide new insights on how to investigate the effects of international crude oil prices on refined and retail fuel prices.

We should note that the input and output prices for the refining sector refer to different products (i.e. crude oil versus unleaded fuel). However, refineries are multi-product firms, producing unleaded fuel, diesel and kerosene, among others. Therefore, apart from the crude oil prices, it could be also the case that the conditions of the other fuel markets also impact their mark-up on the unleaded fuel. This is an issue worth exploring in future work. Further research could also investigate the main drivers of the asymmetric behaviour of refineries mark-up to changes in international crude oil prices so to identify whether such behaviour is led by speculation, collusive behaviour or due to the cost structure of refineries. Another interesting avenue for further study could constitute the identification of asymmetric behaviour based on a time-varying framework, as well as, based on disaggregated data on individual petrol stations, which are scattered around different geographical locations and have different ownership structures. Finally, similar econometric frameworks should be employed to additional countries since the potential asymmetric behaviour by refineries or retailers is a global issue.

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TABLES

Table 1: Selected studies on crude oil prices and their impact on fuel prices.

Authors (year)	Method	Frequency	Symmetric or Asymmetric effects to oil price changes?	Country
Apergis and Vouzavalis (2018)	Non-linear auto-regressive distributed lags	Monthly	Symmetric and asymmetric responses to oil price changes, depending on the country	Italy, Spain, Greece, UK, US
Blair *et al*. (2017)	ECM	Weekly	Asymmetric responses to oil price changes	US regions
Boroumand *et al*. (2016)	Markov-switching regression and MS-ECM	Weekly	Asymmetric responses to oil price changes	France
Chang and Serletis (2016)	Structural GARCH-in-Mean VAR	Monthly	Asymmetric responses to oil price changes	US
Eleftheriou *et al*. (2018)	Asymmetric spatial error correction model	Daily	Asymmetric responses to oil price changes	US
Karagiannis *et al*. (2015)	ECM	Weekly	Symmetric responses to oil price changes	EU countries
Kilian (2010)	SVAR	Monthly	Asymmetric responses to oil price shocks	US
Kristoufek and Lunackova (2015)	ECM, VAR, TAR-ECM	Weekly	Symmetric responses to oil price changes	Various EU countries and US
Liu *et al*. (2010)	ECM	Weekly	Asymmetric responses to oil price changes	New Zealand

Meyler (2009)	VECM	Weekly	Symmetric responses to oil price changes	EU
Qin *et al*. (2016)	Multiple threshold error-correction model	Weekly	Asymmetric responses to oil price changes	US
Radchenko (2005)	VAR	Monthly	Asymmetric responses to oil price volatility	US
Radchenko and Shapiro (2011)	ECM, VAR	Weekly	Asymmetric responses to oil price changes	US
Rahman (2016)	GARCH(1,1)-in-Mean SVAR	Monthly	Asymmetric responses to oil price changes	US
Sen (2003)	Panel regression	Monthly	Symmetric responses to oil price changes	Canada
Valadkhani *et al*. (2015)	Dynamic Least Squares and VECM	Weekly	Asymmetric responses to oil price changes	Australia

Table 2: Descriptive statistics

	PLATTS	*REFINED PRICE*	*RETAIL_PRICE_AT*	*TOTAL_TAXES*
Mean	0.3960	0.4219	1.5086	0.9829
Median	0.3871	0.4124	1.5120	0.9938
Maximum	0.5916	0.6259	1.7140	1.0330
Minimum	0.2314	0.2604	1.2960	0.9205
Std. Dev.	0.0695	0.0707	0.0943	0.0316
Coeff. Var.	0.1755	0.1675	0.0625	0.0321
Observations	1267	1267	1267	1267
	REFINERIES_MARK_UP	*RETAIL_MARK_UP_PT*	*RETAIL_MARK_UP_AT*	
Mean	0.0674	0.2534	0.0742	
Median	0.0635	0.2473	0.0738	
Maximum	0.2321	0.4895	0.1133	
Minimum	0.0030	0.1320	0.0429	
Std. Dev.	0.0293	0.0546	0.0101	
Coeff. Var.	0.4347	0.2154	0.1361	
Observations	1267	1267	1267	

Note: *RETAIL_PRICE_AT* denotes the after-tax retail fuel prices, *RETAIL_MARK_UP_PT* is the retail mark-up in the pre-tax fuel prices, *RETAIL_MARK_UP_AT* is the retail mark-up in the after-tax fuel price. Values are based on prices per litre.

Table 3: Retailers' mark-up (excluding taxes) based on *PLATTS* prices.

	Coefficient	Std. Error	Prob.
γ_0 (Constant)	0.0733	0.0004	0.0000
γ_1 (Dummy)	0.0021	0.0006	0.0005
γ_2 (Slope)	-3.5739	0.2425	0.0000
γ_3 (Slope*Dummy)	0.3341	0.3452	0.3334
Adjusted R-squared		0.4748	
F-statistic		375.3115	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table 4: Retailers' mark-up (including taxes) based on *PLATTS* prices.

	Coefficient	Std. Error	Prob.
γ_0 (Constant)	0.2485	0.0025	0.0000
γ_1 (Dummy)	0.0111	0.0038	0.0039
γ_2 (Slope)	-12.8010	1.4644	0.0000
γ_3 (Slope*Dummy)	0.3328	2.0626	0.8718
Adjusted R-squared		0.2507	
F-statistic		138.9098	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table 5: Retailers' mark-up (including taxes) based on REFINED fuel prices.

	Coefficient	Std. Error	Prob.
γ_0 (Constant)	0.0733	0.0009	0.0000
γ_1 (Dummy)	0.0019	0.0012	0.1056
γ_2 (Slope)	-3.4644	0.4765	0.0000
γ_3 (Slope*Dummy)	0.3666	0.7401	0.6204
Adjusted R-squared		04691	
F-statistic		367.5691	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table 6: Retailers' mark-up (excluding taxes) based on REFINED fuel prices.

	Coefficient	Std. Error	Prob.
δ_0 (Constant)	0.2479	0.0059	0.0000
δ_1 (Dummy)	0.0103	0.0074	0.1645
δ_2 (Slope)	-12.2703	3.0918	0.0000
δ_3 (Slope*Dummy)	-0.4385	4.6852	0.9254
Adjusted R-squared		0.2603	
F-statistic		146.4145	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table 7: Refineries' mark-up based on *PLATTS* prices.

	Coefficient	Std. Error	Prob.
β_0 (Constant)	0.0637	0.0015	0.0000
β_1 (Dummy)	0.0023	0.0022	0.2996
β_2 (Slope)	-3.7042	0.3144	0.0000
β_3 (Slope*Dummy)	-1.4983	0.6436	0.0201
Adjusted R-squared		0.7347	
F-statistic		1162.1230	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

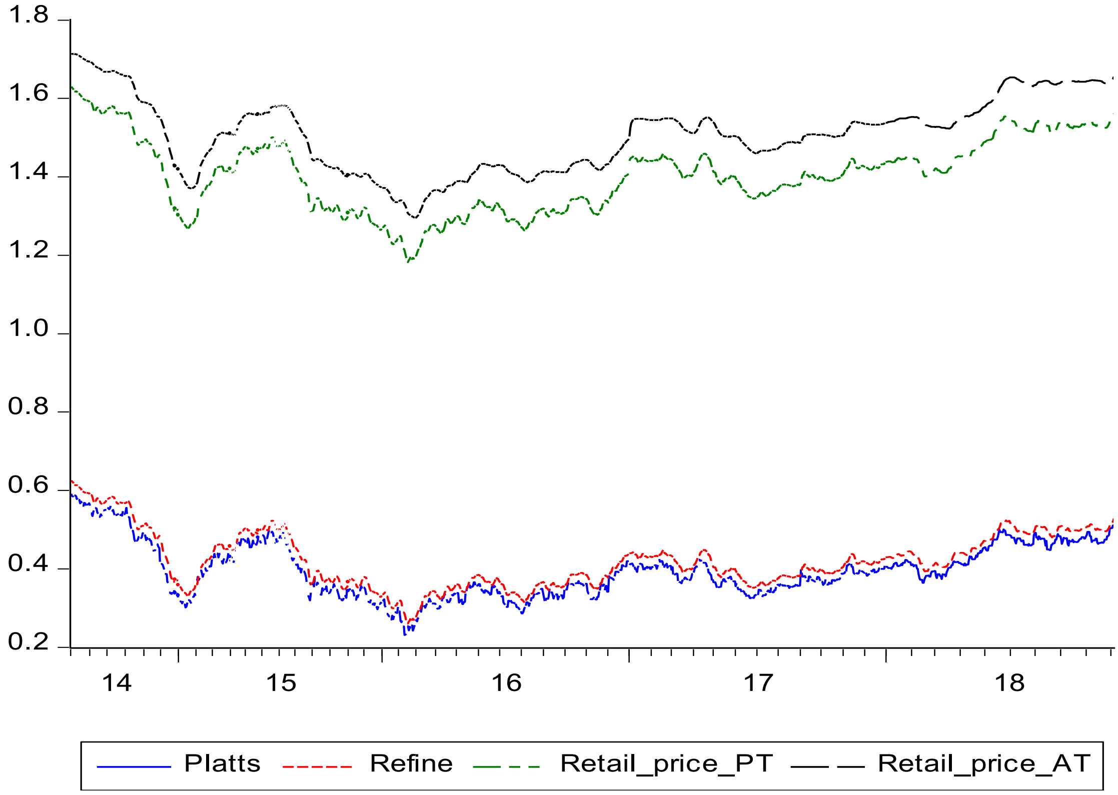
Table 8: Analysis at weekly and monthly frequency: Refineries' mark-up based on *PLATTS* prices.

	Weekly			Monthly		
	Last observation					
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
β_0 (Constant)	0.0693	0.0039	0.0000	0.0627	0.0006	0.0000
β_1 (Dummy)	-0.0045	0.0056	0.4186	0.0101	0.0062	0.1114
β_2 (Slope)	-0.0508	0.1842	0.7829	-0.0286	0.1608	0.8597
β_3 (Slope*Dummy)	-0.1551	0.2910	0.5946	0.0224	0.2344	0.9241
Adjusted R-squared		-0.0064			0.0531	
F-statistic		0.5291			1.9173	
Prob(F-statistic)		0.6627			0.1399	
	Weekly			Monthly		
	Average observations					
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
β_0 (Constant)	0.0629	0.0055	0.0000	0.0615	0.0075	0.0000
β_1 (Dummy)	-0.0041	0.0072	0.5723	0.0030	0.0104	0.7745
β_2 (Slope)	0.4214	0.3873	0.2778	0.0377	0.1901	0.8436
β_3 (Slope*Dummy)	-0.9421	0.5189	0.0709	-0.0577	0.2948	0.8455
Adjusted R-squared		0.0166			-0.0629	
F-statistic		2.2387			0.0332	
Prob(F-statistic)		0.0847			0.9917	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

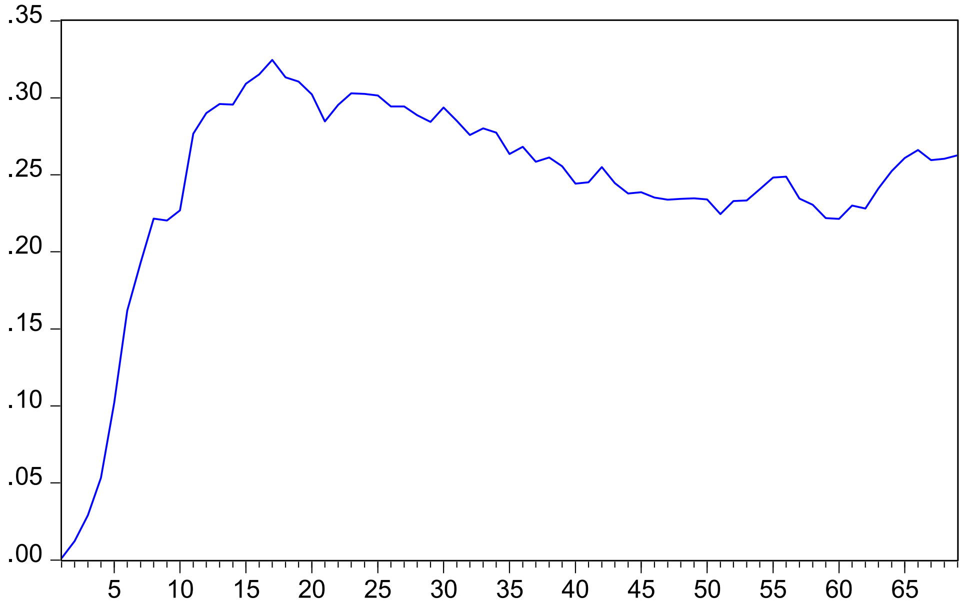
FIGURES

Figure 1: Visual representation of the series.



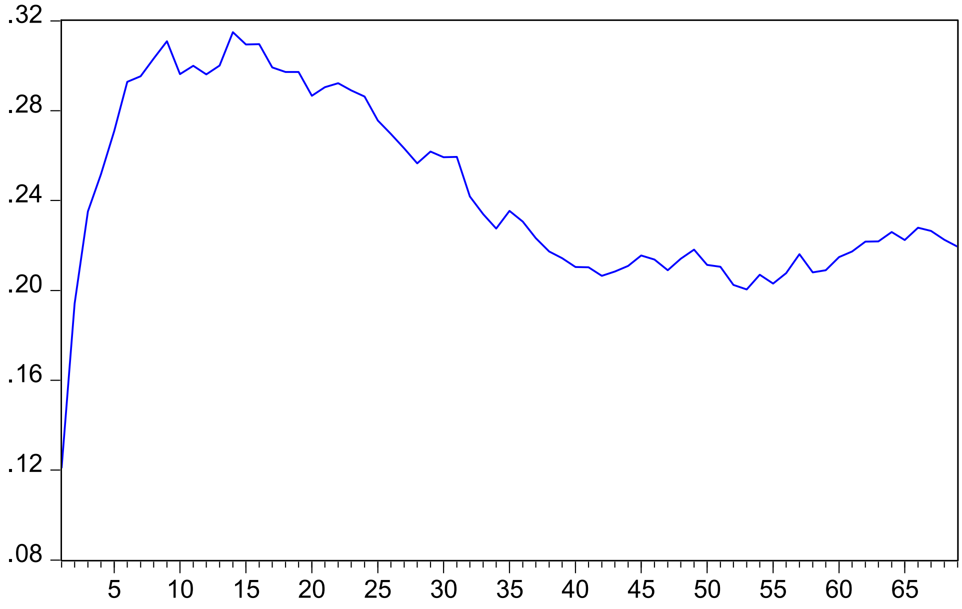
Note: Retail_price_PT refers to the pre-tax retail fuel prices, whereas Retail_price_AT denotes the after-tax retail fuel prices.

Figure 2: The $\max_{K}\left(1-\frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret\_tax)}-\bar{y}^{(ret\_tax)}\right)^2}\right)$ for modelling the retailers' mark-up including the taxation effect.



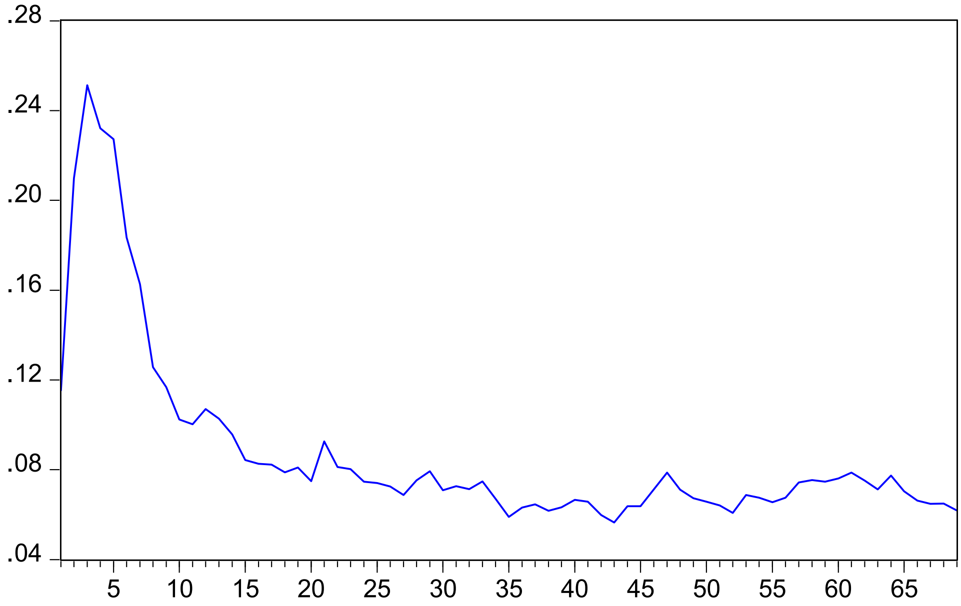
Note: The line shows the adjusted R-squared for the model in equation 1 (based on *PLATTS* prices) at each *K*=1,..,70 day. The x-axis denotes the most recent days and the y-axis refers to the adjusted R-squared.

Figure 3: The $\max_{K}\left(1-\frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret\_tax)}-\bar{y}^{(ret\_tax)}\right)^2}\right)$ for modelling the retailers' mark-up including the taxation effect.



Note: The line shows the adjusted R-squared for the model in equation 1 (based on refined fuel prices) at each *K*=1,..,70 day. The x-axis denotes the most recent days and the y-axis refers to the adjusted R-squared.

Figure 4: The $\max_K \left(1 - \frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ref)} - \bar{y}^{(ref)}\right)^2}\right)$ for modelling the refineries' mark-up.



Note: The line shows the adjusted R-squared for the model in equation 9 at each *K*=1,..,70 day. The x-axis denotes the most recent days and the y-axis refers to the adjusted R-squared.

Figure 5: Scatterplot between the refineries' mark-up and the first difference in average *PLATTS* prices per litre.

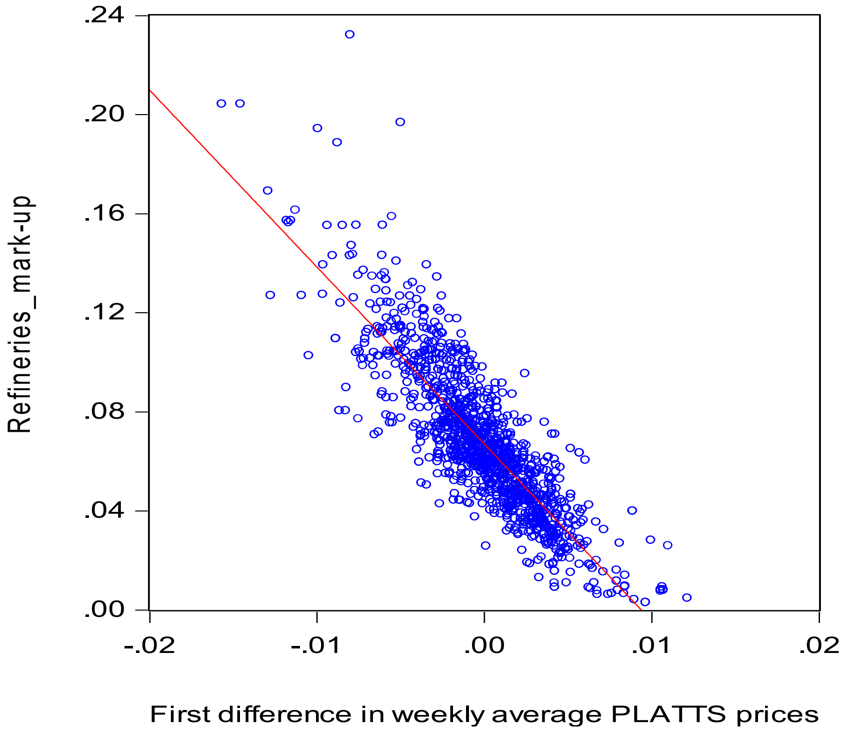
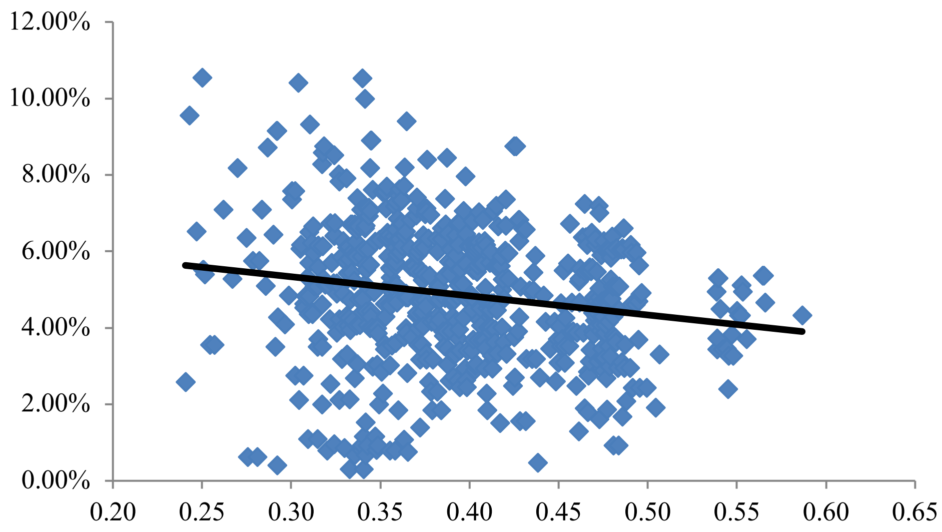
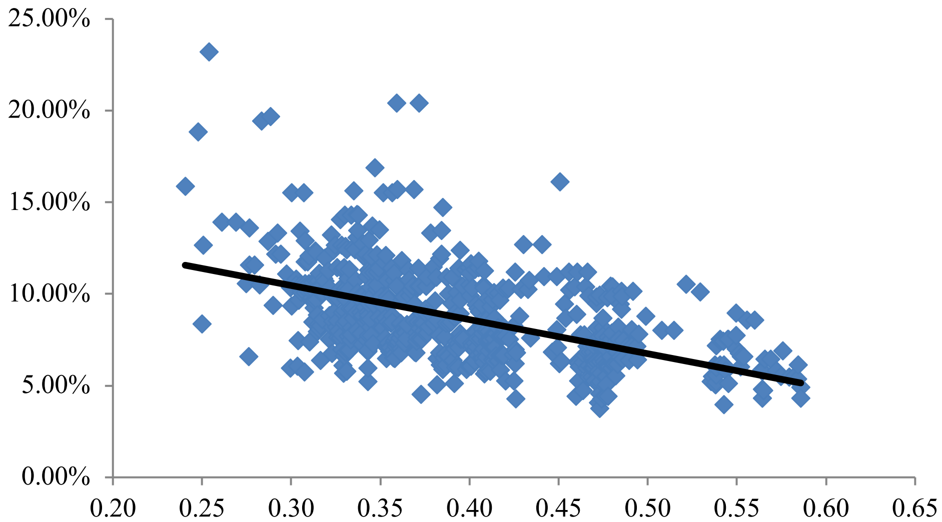


Figure 6: Scatterplot between the refineries' mark-up and increasing/decreasing average *PLATTS* prices per litre.

Increasing average *PLATTS* prices



Declining average *PLATTS* prices



Note: The x-axes denote the 5-days moving average *PLATTS* prices per litre and the y-axes denote the refineries' mark-up.

APPENDIX

Table A1: Retailers' mark-up (excluding taxes) based on *PLATTS* prices.

	Coefficient	Std. Error	Prob.
γ_0 (Constant)	0.0710	0.0002	0.0000
γ_1 (Dummy)	0.0057	0.0009	0.0000
γ_2 (Slope)	-4.4692	0.2259	0.0000
γ_3 (Slope*Dummy)	1.8789	0.4338	0.0000
Adjusted R-squared		0.4790	
F-statistic		373	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table A2: Retailers' mark-up (including taxes) based on *PLATTS* prices.

	Coefficient	Std. Error	Prob.
γ_0 (Constant)	0.2394	0.0013	0.0000
γ_1 (Dummy)	0.0375	0.0060	0.0000
γ_2 (Slope)	-15.986	1.3220	0.0000
γ_3 (Slope*Dummy)	9.0100	2.4875	0.0003
Adjusted R-squared		0.2949	
F-statistic		172	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table A3: Retailers' mark-up (including taxes) based on REFINED fuel prices.

	Coefficient	Std. Error	Prob.
γ_0 (Constant)	0.0725	0.0007	0.0000
γ_1 (Dummy)	0.0035	0.0015	0.0199
γ_2 (Slope)	-3.7674	0.4858	0.0000
γ_3 (Slope*Dummy)	0.8228	0.8471	0.3199
Adjusted R-squared		0.4493	
F-statistic		337	
Prob(F-statistic)		0.0000	

Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table A4: Retailers' mark-up (excluding taxes) based on REFINED fuel prices.

	Coefficient	Std. Error	Prob.
δ_0 (Constant)	0.2436	0.0045	0.0000
δ_1 (Dummy)	0.0219	0.0091	0.0161
δ_2 (Slope)	-13.191	3.1669	0.0000
δ_3 (Slope*Dummy)	2.3252	4.8817	0.6339
Adjusted R-squared		0.2782	
F-statistic		159	
Prob(F-statistic)		0.0000	

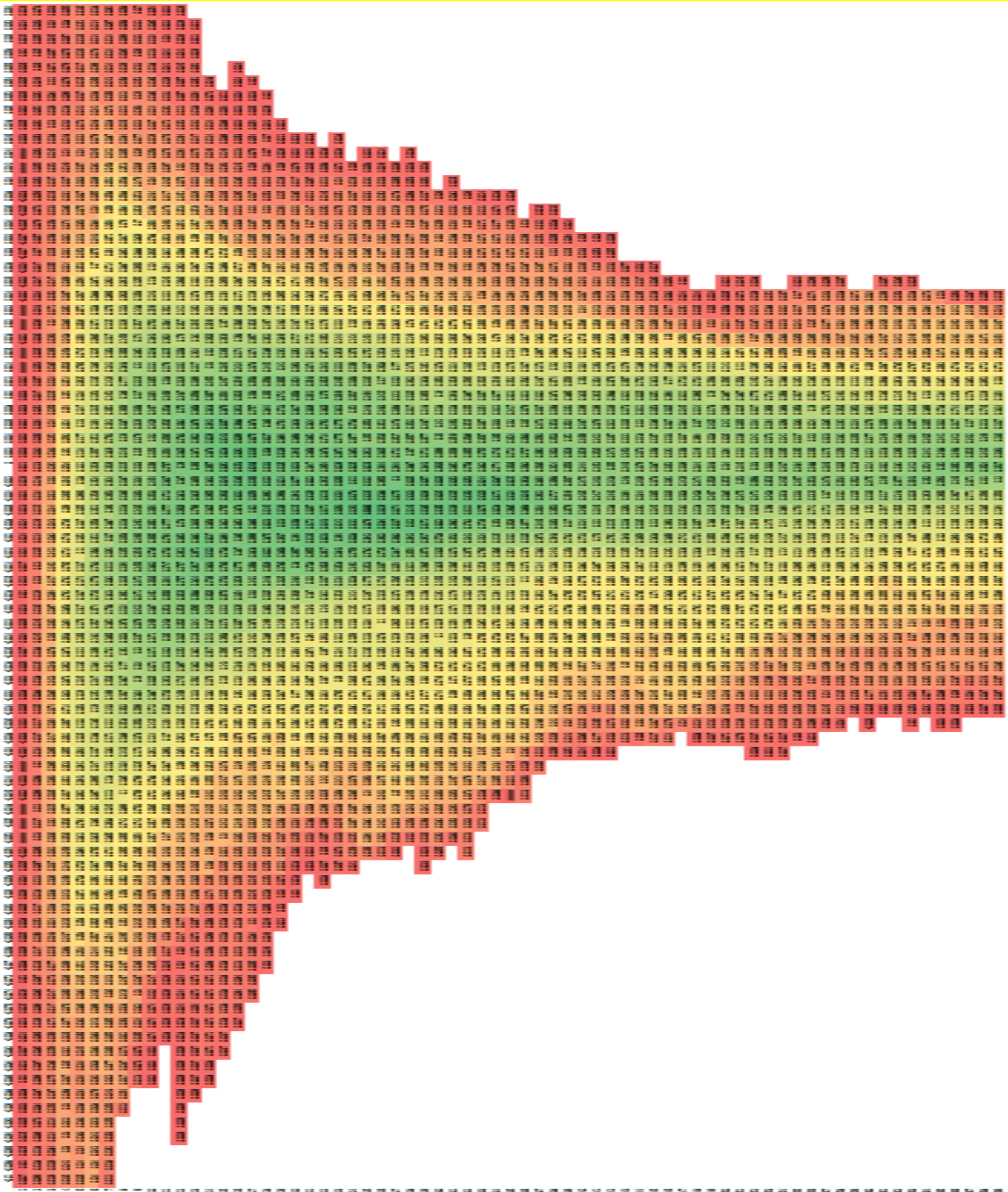
Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Table A5: Refineries' mark-up based on *PLATTS* prices.

	Coefficient	Std. Error	Prob.
β_0 (Constant)	0.0609	0.0011	0.0000
β_1 (Dummy)	0.0020	0.0028	0.4788
β_2 (Slope)	-3.7527	0.2793	0.0000
β_3 (Slope*Dummy)	-1.2956	0.7031	0.0656
Adjusted R-squared		0.4237	
F-statistic		308	
Prob(F-statistic)		0.0000	

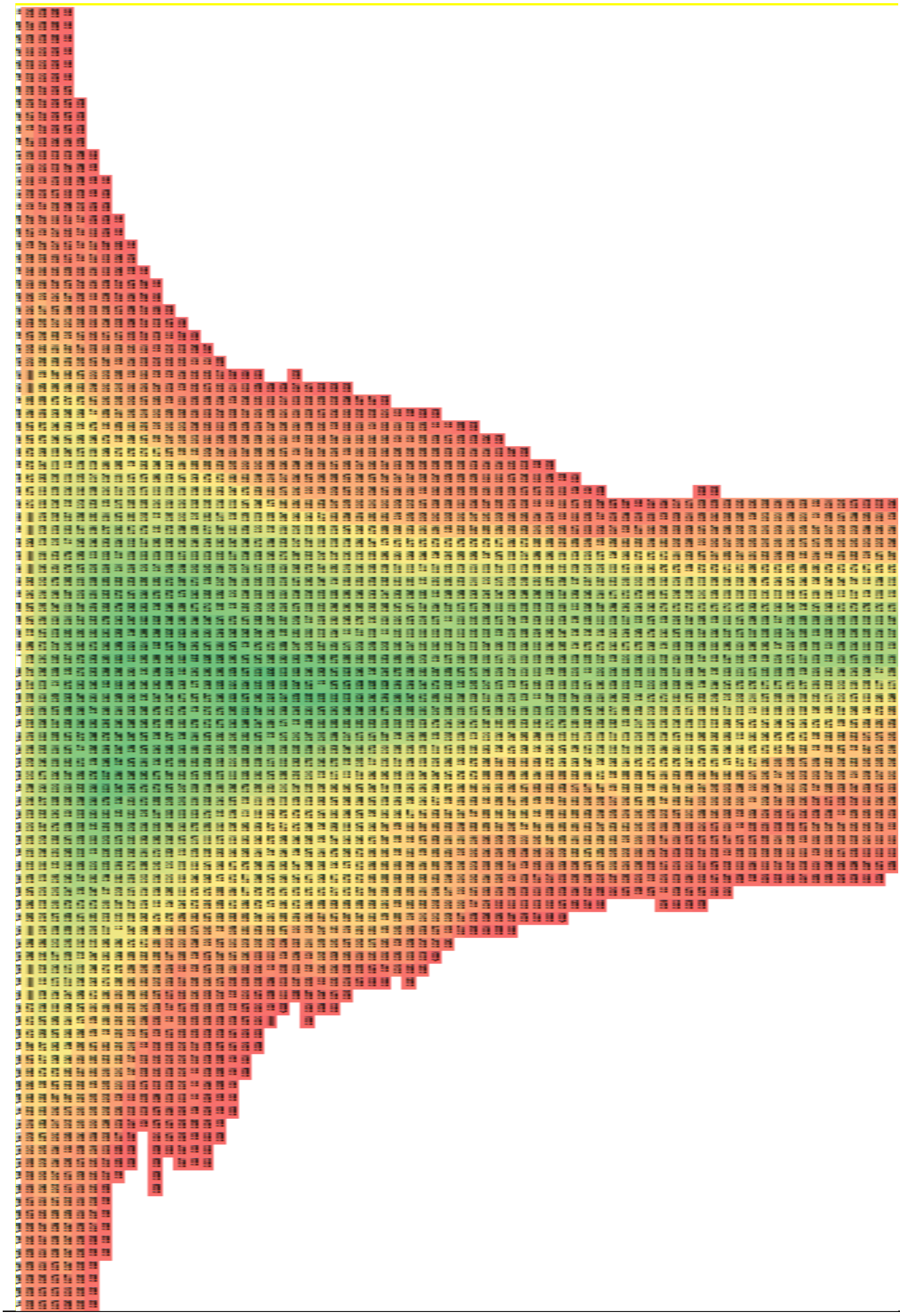
Note: HAC heteroscedasticity and autocorrelation robust standard errors are used.

Figure A1: The heat map of $\max_{K,\omega}\left(1-\frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret\_tax)}-\bar{y}^{(ret\_tax)}\right)^2}\right)$ for modelling the retailers' mark-up based on Platts prices.



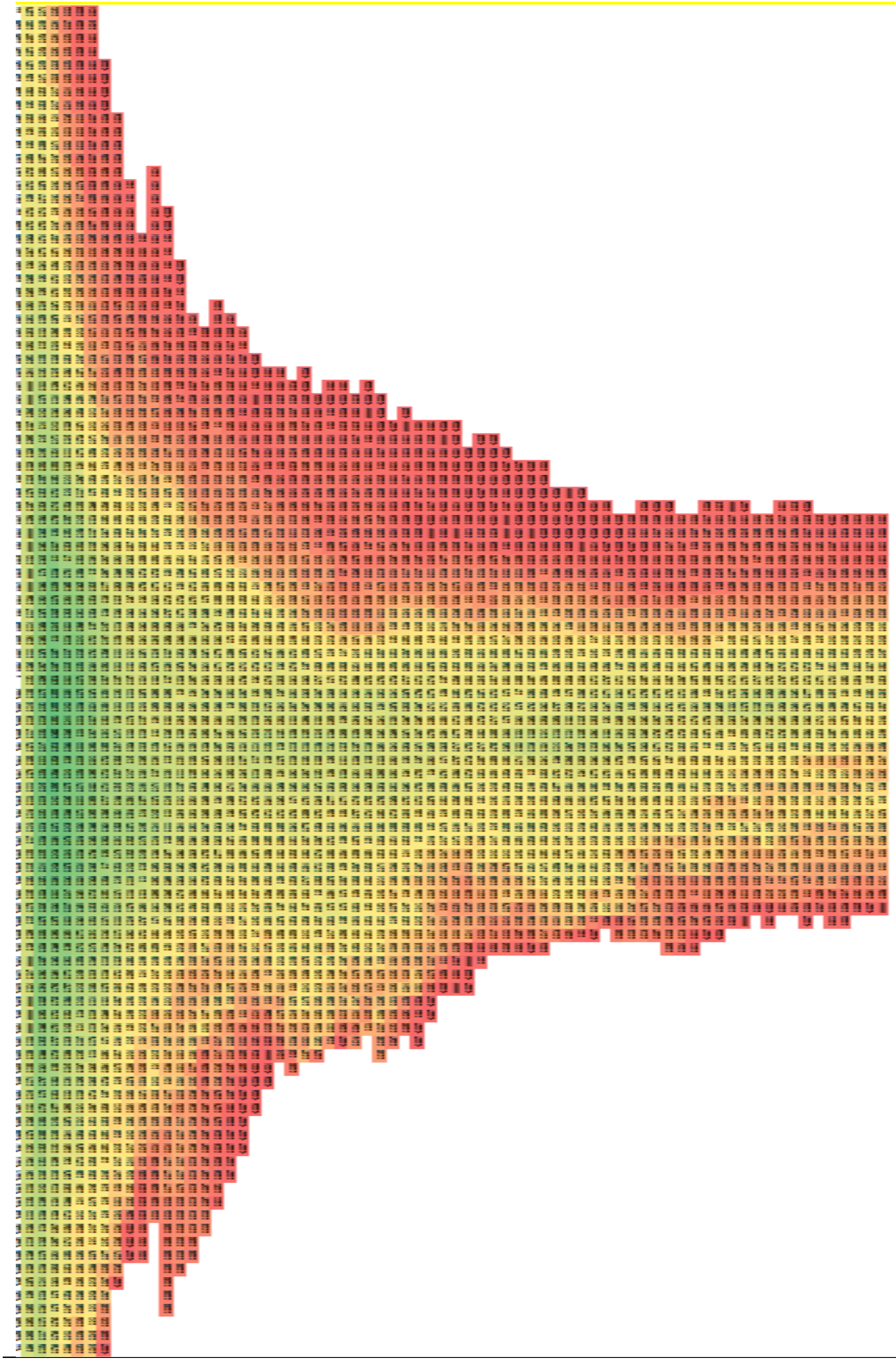
Note: The green(red) colour shows the highest(lowest) values of $\max_{K,\omega}(.)$. The x-axis refers to the values of K, for $K \ni [0,70]$ whereas the y-axis refers to the values of ω, for $\omega \ni [-0.01,0.01]$.

Figure A2: The heat map of $\max_{K,\omega}\left(1-\frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ret\_tax)}-\bar{y}^{(ret\_tax)}\right)^2}\right)$ for modelling the retailers' mark-up based on refined fuel prices.



Note: The green(red) colour shows the highest(lowest) values of $\max_{K,\omega}(.)$. The x-axis refers to the values of K, for $K \ni [0,70]$ whereas the y-axis refers to the values of ω, for $\omega \ni [-0.01,0.01]$.

Figure A3: The $\max_{K,\omega}\left(1-\frac{\sum_{t=1}^{T}(\hat{u}_t^2)}{\sum_{t=1}^{T}\left(y_t^{(ref)}-\bar{y}^{(ref)}\right)^2}\right)$ for modelling the refineries' mark-up based on platts prices.



Note: The green(red) colour shows the highest(lowest) values of $\max_{K,\omega}(.)$. The x-axis refers to the values of K, for $K \ni [0,70]$ whereas the y-axis refers to the values of ω, for $\omega \ni [-0.01,0.01]$.