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Evidence about Asymmetric Price Transmission in the main European Fuel Markets: From TAR-ECM to Markov-Switching approach.

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Abstract

This paper presents new evidence on the existence of asymmetries in the transmission of shocks in oil prices in the main European fuel markets and their relation to the so-called "rockets and feathers effect". Our approach differs from the existing literature in two ways: i) The data used: we use forward prices rather than spot prices because fuel leaders use forward contracts to buy crude oil. ii) The methodological approach is different. We adopt a more sophisticated econometric model, the Markov-Switching model, and use it to contrast the robustness of the results obtained with the TAR-ECM methodology with an endogenous threshold (non-zero threshold). In general, the results show evidence of an asymmetric response of gasoline and diesel prices to changes in the price of crude oil, both in the short-run as well as with respect to the adjustment towards long-run equilibrium. These price asymmetries fall in line with the "rockets and feathers" hypothesis.

JEL Classification: C01, C51, D43, Q40

Keywords: price asymmetries, crude oil prices, TAR-ECM, Markov-switching estimation, 'rockets and feathers' behavior.

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1. Introduction

The impact on economic activity of the changes in energy prices, in general, and oil, in particular, has aroused the interest of economists for decades. This is largely because empirical evidence shows that recessions of varying magnitude have followed important increases in oil prices linked to different events such as the embargo from producing countries (OPEC) from 1973 to 1974, the Iranian revolution of 1978, the Iran-Iraq war in 1980 or the Gulf War in 1990. It is therefore reasonable to believe that energy is a strategic good for any economic activity. However, the great energetic dependence of European economies harms competitiveness and energetic safety in the medium and long-term.

Europe's current dependence on foreign oil is around 54%, of which 99% corresponds to oil products. The energetic dependence among the main European markets is: Italy 76%, Germany 61.5%, France 46% and UK 45.5%.

In this sense, the volatility that has been rocking the oil market in recent years has drawn attention on how this variable affects the different economies and, more specifically, how it affects the petrol and diesel markets in different countries. The increase in fuel costs for consumers and in profits for oil companies has generated "significant public and political attention" (Hale and Twomey, 2008) and has reignited the debate on the pricing of petrol and diesel products. Within this context, the so-called "rockets and feathers" behaviour is relevant for countries depending on foreign oil. Given that these prices are exogenous, these countries are particularly exposed to large volatilities in crude oil prices and these prices undoubtedly have an impact on citizen welfare.

Oil companies transfer increases in international oil prices to local markets significantly faster than they do with decreases. This is a well-known phenomenon and, as a consequence of this retail price volatility, consumers have become more wary about the price-setting behaviour of oil companies. In other words, consumers tend to believe that oil companies adjust petrol and gasoil retail prices more quickly for cost increases than they do for cost decreases. These adjustments, which differ according to direction, are known as price asymmetries (Bettendorf et al., 2003).

One possible explanation is related to the lack of competition in the market for oil products. Generally, when a market is perfectly competitive, standard economic theory claims that increases or decreases in input prices should translate into symmetric changes in retail prices. In this sense, the market structure for oil prices differs among the main European countries (Karagiannis et al. 2015). We would therefore also expect responses in retail prices to differ.[1]

The possible asymmetric transfer of raw material price variations to the price of the final product is a widely analyzed phenomenon in the literature, not only in the petroleum sector but also in many other markets (Peltzman 2000). Focusing more specifically on the oil market, numerous studies on oil pricing asymmetries forming part of the so-called "rockets and feathers" behaviour examine whether retail prices rise faster than they fall in response to changing oil prices. Many of these studies, using a wide range of econometric approaches, have been applied to gasoline markets in different countries but the results have been nonconclusive. To this respect, as Shin (1994) points out, the contradictory results found in these papers could be explained by the lack of homogeneity in the data, rather than the different models used.

In consequence, taking homogeneous data, this paper aims to analyze the potential asymmetric response in the Main European Fuel Markets (Germany, U.K., France and Italy) of retail prices for gasoline and diesel fuel to changes in crude oil prices, and its relation to the so-called 'rockets and feathers' behaviour. We concentrate on these four European economies because only a few recent studies in the relevant literature deal with the issue of oil price transmission for European Economies jointly and because these countries are the four largest retail fuel markets in the EU.

Our paper principally differs from previous work along various dimensions:

i) Unlike the aforementioned work, we use forward prices for crude oil instead of spot data given that fuel leaders use forward contracts in the international oil market to hedge against crude oil volatility. Moreover, we also use a longer future because the oil refining process and the subsequent distribution of oil products to gas stations takes time. A three-month future captures this temporal lag.

[1] The different level of competition between the countries or between the oil segments within the same country (refining, wholesale and retail segments) may trigger price volatility, which in turns may lead to price behaviour asymmetry (Polemis and Panagiotis 2013). However, Pelztman (2000) found no clear link between competition and asymmetric price transmission.

ii) Our econometric methodology differs from that of the mainstream literature. While most of the papers use different methodologies imposing a zero threshold in the variation rate of oil prices to test for asymmetric responses, we estimate it endogenously. More precisely, we estimate a model that allows for the possibility of changing response rates when passing a non-zero threshold rather than the typical zero thresholds[2]. We are interested in determining whether the transmission of oil price changes on retail prices is faster or slower depending on the size of such variation in the price of crude oil, which may be above or below zero.

iii) We develop a robustness test for the results obtained with the TAR-ECM estimation by using a two-regime Markov-switching model as an alternative for estimating the non–linear dynamic relationship between the crude oil price and the retail price for gasoline and diesel. We propose this methodology because i) this type of model has never been used to characterize asymmetric price responses for the economies considered in this paper[3] and ii) this methodology improves the analysis in several dimensions. In this sense, TAR models are subject to the following restrictions: i) the regimes are determined by observable variables, so it is up to the researcher to select the variable or set of variables that determines the outcome in one or another regime; ii) the regime is determined by the value of the selected variable relative to a threshold value, which is constant for the entire sample; this restriction may be important when the sample includes structural breaks. By contrast, in the Markov-Switching models the state of the regime is unobservable; the data and procedures for non-linear maximum likelihood estimation are the only ones that identify the different regimes, without having been imposed by the researcher one *a priori* hypothesis regarding the driving forces behind the regime-switching, i.e. in our case, no *a priori* hypothesis on asymmetric price responses has been imposed. From this point of view,

[2] Only Grasso and Manera (2007) estimate an endogenous threshold to detect price asymmetry in the gasoline market. Contrary to our results, their results are inconclusive and they find significant and positive values for the threshold in function of the stage under study (refinery, distribution or both). We, however, find negative and significant threshold values across all the countries both for the gasoline and diesel market.

[3] Boroumand et al. (2016) also use the Markov-switching approach for the diesel market in the French economy. However, they use the switching approach in a first stage to identify two samples according to the volatility of crude oil price. Once the sample is split in two, according to low or high volatility, they apply the traditional exogenous threshold methodology (positive or negative) to identify possible asymmetries in the behaviour of prices in each of the samples. By contrast, our work uses Markov-switching to characterize asymmetries in the whole dynamics of the transmission mechanism, i.e., in our case, the estimated parameters of the dynamic relation between retail and crude oil prices are regime-switching, obtained by implementing the Markov-switching methodology.

these models are less restrictive even though the estimated regimes may sometimes be difficult to identify and interpret. Different unobservable Markov processes, regardless of whether or not they are independent, may be incorporated so that, for example, the model parameters can follow the same process and the variance of model disturbances may follow a different one (also a different number of regimes can be assumed for parameter and error variance).

The results of our paper indicate evidence of asymmetric response of both gasoline and diesel prices to changes in the price of crude oil in the short-run as well as with respect to the adjustment speed towards the long–run equilibrium. These asymmetries generally fall in line with the rockets and feathers hypothesis. One major finding of the paper is that the Markov-switching methodology, given its flexibility, reveals asymmetric responses that the TAR-ECM approach is incapable of identifying under the same circumstances.

The rest of the paper is organized as follows. In section 2 we review the relevant literature in this field. Section 3 describes the data and the methodology used for the study. Section 4 presents the results obtained and section 5 concludes.

2. Literature review

Over the last years, a great number of studies have focused on the existence of price asymmetry in the gasoline market with controversial results. They analyze different countries individually using different time periods, frequency of data, econometric methodologies, determinants of this asymmetry, and so forth (Polemis, 2012).

Different studies look at the gasoline market in the U.S. One of the most influential and contributing papers on this topic is Borenstein et al. (1997). In this paper the authors find, through econometric time series analysis, that retail prices respond more quickly to increases than to decreases in crude oil prices in USA. Other papers applied to the US economy using other econometric specifications to find evidence of asymmetries are Balke, Brown and Yucel (2001), Radchenko (2005a), Al-Gudhea, Kenc and Dibooglu (2007) and Pal and Mitra (2015)[4] among others. By contrast, the papers of Bachmeier and Griffin (2003) and Douglas (2010) find no evidence of asymmetries in the US economy.

In terms of asymmetries in different European countries, the seminal paper on “rockets and feathers” behaviour is Bacon (1991). This author uses biweekly data to find evidence of an asymmetric price adjustment process in the UK gasoline market. The paper of Reilly and Witt (1998) also makes the same finding. Kirchgassner and Kübler (1992) focus on gasoline and fuel oil in Germany but their results are nonconclusive. The results of Asplund et al. (2000) in their study on the Swedish gasoline market are also nonconclusive. Likewise, the results of Bettendorf et al. (2003) also follow the same line concerning the Dutch gasoline market. The main papers analyzing the existence of asymmetric price transmission for the Spanish economy are Contín-Pilar et al. (2009) and Balaguer and Ripollés (2012), among others, encountering no evidence of asymmetric behaviour. Concerning the French economy, the work of Lamotte et al. (2013) and Boroumand et al. (2016) are worth pointing out. Both papers reveal an asymmetric response of gasoline prices to shocks in the crude oil price.

As mentioned in the introduction, the contradictory results found in these papers could be explained by a lack of homogeneity in the data rather than the different models used. In this sense, only a few recent studies in the relevant literature deal with the issue of oil price transmission applied to European Union economies jointly.

Galeotti et al. (2003) re-examines the issue of asymmetries in the transmission of shocks to crude oil prices on the retail price of *gasoline* by allowing for a possibly asymmetric role of the exchange rate. For this analysis they use an asymmetric error-correction model and consider different stages for the transmission mechanism (refinery stage, distribution stage or single stage). The results are mixed; they find the asymmetries in different stages in function of the country. Considering their ´single stage´ analysis, the closest to ours, they find evidence of rockets and feathers behaviour for France, both in the short-run and the long run, while for Germany and United Kingdom they find evidence only in the short-run.

[4] This paper uses a methodology similar to the TAR-ECM of our paper, with the difference that the multiple estimated thresholds are exogenous.

Grasso and Manera (2007) analyze price asymmetries in the *gasoline* market by investigating the sensitivity of the empirical results to the choice of a particular econometric specification. They estimate three different econometric models (namely asymmetric ECM, autoregressive threshold ECM, and ECM with threshold cointegration). They also consider three different stages in line with Galeotti et al. (2003). Yet their results are inconclusive; they find that the type of market and the number of countries which are characterized by asymmetric oil–gasoline price relations vary across models. They estimate endogenous thresholds for a TAR-ECM model similar to ours; focusing on their ´single stage´ model, the most similar to ours, they find large differences, in both sign and magnitude, for the estimated thresholds of the countries analyzed (France, Germany, Italy, Spain and UK).

Polemis and Panagiotis (2013) use the generalized method of moments (GMM) in a panel data set to estimate asymmetric error correction models (ECM); they split the sample according to the positive or negative values for the variation rates of oil prices, exchange rate and the error correction term. In this manner, the study measures the asymmetries in the transmission of shocks to input prices and exchange rate on the wholesale and retail *gasoline* prices. Their results signal that these prices respond asymmetrically to cost increases and decreases.

Karagiannis et al. (2015) examine the nature of price adjustments in the *gasoline* and *diesel* markets using a "decomposed" Error Correction Model which considers positive or negative changes in the prices of international crude. They find that symmetry prevails in the retail markets of all the countries under study. Therefore, this paper finds no evidence in support of the "rockets and feathers" behaviour. In the same line, the European Central Bank (2010) finds no evidence of significant asymmetries in petrol and diesel markets in the Euro-area.

After this revision, we can conclude that there is no consensus in the empirical literature for European Economies on price asymmetries and its relation to the "rockets and feathers" hypothesis. In other words, evidence concerning the symmetric adjustment of retail fuel prices to crude oil prices is inconclusive.

Our article contributes to filling a gap in the recent literature in the following way: we first use forward price data for crude oil because fuel dealers use forward contracts to cover against the changes in oil prices. Secondly, we endogenize the rise or fall of oil prices for which these prices changes are transmitted asymmetrically to the prices of gasoline and diesel. So far, most of the results regarding the presence of asymmetries have been based on the ad-hoc assumption of their existence when oil price growth was positive or negative. We assume that this starting hypothesis could be inaccurate in some circumstances, making it difficult to obtain the asymmetry result. In this sense, our approach is somewhat similar to the TAR-ECM single-stage analysis in Grasso and Manera (2007), with the difference of the forward prices for crude oil conveniently transformed into euros by using the exchange rate. In contrast to Grasso and Manera results, we find similar values for the non-zero threshold (in sign and level) for all the countries under study. Using this methodology, we find asymmetric price responses in the diesel market for all the countries analyzed, both in the short-run and long-run for France and Italy, only in the short run for Germany and only in the long-run for UK. However, only the long-run asymmetries seem to be in line with the rockets-feathers pattern. Yet using this methodology we did not find any evidence of asymmetries in the gasoline market.

In a second stage of the analysis, we check the results found with the TAR-ECM approach using the Markov-Switching model. To the best of our knowledge, this type of methodology has not been applied to detect asymmetric responses of retail prices to oil price shocks in a European country. One major conclusion of this exercise is that the Markov-switching methodology is able to unveil asymmetric behaviours that the TAR-ECM model did not identify. Specifically, the most remarkable difference with the null evidence found using the TAR-ECM approach is the evidence of rockets and feathers patterns found both in the short-run and in the long-run behaviour of retail prices for the gasoline market in the four countries. With respect to the gasoil market, the asymmetric behaviour evidence found using TAR-ECM is confirmed.

3. Data and Methodology

3.1 Data

Analyzing the asymmetric response of retail fuel market to changes in the price of crude oil requires a number of choices to make in terms of the data for the four main European economies considered, Germany, U.K., France and Italy.

In this sense, we use weekly data for: i) Crude Oil-Brent price, 3 Months Forward (free on board) US Dollar per barrel, which is conveniently transformed into euros by using the dollar to euro 3 month forward exchange rate, ii) price before taxes, in euros, of gasoline per 1000 litres and iii) price before taxes, in euros, of diesel per 1000 litres.

The complete sample covers the period January 2005 to November 2013. The sources of the data are Datastream for oil price and exchange rate, and European Weekly Oil Bulletin for gasoline and diesel prices.

Forward oil prices are used instead of spot prices because fuel dealers use forward contracts to buy crude oil, so this one seems to be the relevant variable to fix the retail price of gasoline and diesel. On the other hand, the survey conducted by Grasso and Manera (2007) shows that "66.7% of the studies which support the presence of asymmetric price behaviour employ net-of-tax gasoline prices, that is, asymmetries emerge more easily once the fiscal veil is removed". We use this evidence to choose the pre-tax retail data. Moreover, taxes are out of retailers' control[5].

3.2 Unit roots, Causality and Cointegration Test

In order to carry out the estimation of the Error Correction Models used to describe the dynamic relation between crude oil Price and the retail prices of fuel (gasoline and gasoil), we must previously check the integration order of the variables involved as well as the existence of a cointegration relation between oil and retail prices.

We use standard tests to check that all the price series are I(1), such as the Augmented Dickey-Fuller (ADF) or Phillips-Perron (PP) to test for the null hypothesis of one unit root. We also use the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test to carry out the null hypothesis of stationarity, I(0). Additionally, we implement the unit root test with structural breaks of Perron (1997), which seems appropriate given the structural break in the data due to the crisis. The null hypothesis of unit root is not rejected whenever the test is larger than the tabulated critical values, while the null

[5]Given the different fiscal systems which characterize the countries under analysis, this choice will ease the comparison of the empirical findings between economies.

hypothesis of stationarity is not rejected whenever the test is lower than the critical values.

From Table 1, we can conclude that the null hypothesis of one unit root cannot be rejected for gasoline or diesel for any country and, accordingly, the null hypothesis of stationarity is rejected for both gasoline and diesel for all the countries.

On the other hand, to check the assumption of statistical causality from crude oil price towards the retail prices, we carry out Granger causality tests by estimating bivariate autoregressive models for the gasoline price and the crude oil price as well as for the gasoil price and the crude oil price (eight lags have been used in both cases).

In Table 2 we show the χ^2 test, with its p-value in brackets, to check for causality from oil price towards gasoline (or gasoil) price and vice versa. Actually, only causality from crude oil towards the retail price is relevant, so we only need to focus on the lines corresponding to the retail prices as dependent variables. In all the cases the p-value is close to zero; so the null hypothesis of causality from crude oil price towards the retail prices, gasoline and gasoil, cannot be rejected in any of the countries.

Finally, we check for the existence of cointegration, long-term relationships, between the price of gasoline or diesel and the forward price of oil. To study these relationships, we use the "ARDL bounds" that test the cointegration of these variables from the perspective developed by Pesaran et al. (2001). The advantage of this approach is that it is unrestrictive; it can be applied to regressors I(0) or I(1) or fractionally integrated. Moreover, unlike other multivariate cointegration approaches, it uses a sole equation in reduced form.

This test consists in estimating an “unrestricted error correction model” by ordinary least squares (OLS) as follows:

$$\nabla x_k = c_k + \alpha_{1,k} x_{k,t-1} + \alpha_{2,k} p_{t-1} + \sum_{i=1}^{I} \beta_{i,k} \nabla x_{k,t-i} + \sum_{j=1}^{J} \gamma_{j,k} \nabla p_{t-j} + u_t \qquad (1)$$

$$k = \{gasoline, diesel\}$$

where $x_{k,t}$ is the price of gasoline (diesel) if k={*gasoline,diesel*}, p_t is the price of oil.

Once we estimate the equation (1), after identifying *I* and *J*, we test the null hypothesis $H_0: \alpha_{1,k} = \alpha_{2,k} = 0$ using an *F*-test both for the gasoline and diesel equations. The lower band of the test developed by Pesaran (2001), implies that the regressors are I(0), while the upper band implies that all the regressors are I(1). If the resulting *F* is over the upper band, we reject the null hypothesis and have cointegration. If *F* is below the lower band, we cannot reject the hypothesis and we conclude that cointegration is absent. Finally, if *F* is between the upper and lower bands, the inference is non-conclusive.

Once we have tested and accepted the presence of cointegration, we may estimate the long-term model as follows:

$$x_{k,t} = c_k + \sum_{i=1}^{I} \alpha_{1,k} x_{k,t-i} + \sum_{i=0}^{J} \alpha_{2,k} p_{t-i} + \varepsilon_{k,t}, \quad k = \{g, d\} \qquad (2)$$

We use the OLS estimate of error correction mechanism throughout the rest of this paper. Table 3 shows the results of the *F* test for each of the countries under study. We can conclude that, in all the cases, the existence of cointegration cannot be rejected at significance levels of 5% or 1%.

[Insert Tables 1, 2 and 3]

3.3 Econometric Methods

3.3.1 TAR-ECM model

As a first approach, we estimate for the four countries considered, a “Threshold autoregressive Error Correction Model” (TAR-ECM), in which the retail fuel prices are explained through their own lags and the crude oil forward price as an exogenous variable.

We formulate two causality regimes and allow that the estimation procedure endogenously estimate the threshold value for the variation rate of crude oil price that determines the jump from the first to the second regime. Based on the results of the previous subsection 3.2, the econometric model we estimate is:

$$\nabla x_{jt} = \left[\delta^{(1)}\hat{\varepsilon}_{t-1} + \beta^{(1)} + \sum_{i=1}^{p}\rho_i^{(1)}\nabla x_{jt-1} + \sum_{l=0}^{q}\gamma_l^{(1)}\nabla p_{t-l}\right] Ind(\nabla p_t > \overline{c}) +$$

$$\left[\delta^{(2)}\hat{\varepsilon}_{t-1} + \beta^{(2)} + \sum_{i=1}^{p}\rho_i^{(2)}\nabla x_{jt-1} + \sum_{l=0}^{q}\gamma_l^{(2)}\nabla p_{t-l}\right]\left(1 - Ind(\nabla p_t > \overline{c})\right) + \zeta_t \qquad (3)$$

for *j*={gasoline, diesel}, where $\left\{\delta^{(1)}, \beta^{(1)}, \rho_1^{(1)}, \dots, \rho_p^{(1)}, \gamma_1^{(1)}, \dots, \gamma_q^{(1)}\right\}$, are the parameters corresponding to the first regime and $\left\{\delta^{(2)}, \beta^{(2)}, \rho_1^{(2)}, \dots, \rho_p^{(2)}, \gamma_1^{(2)}, \dots, \gamma_q^{(2)}\right\}$ the ones corresponding to the second regime, $\hat{\varepsilon}_t$ are the residuals of the cointegration equation (2), ∇ denotes first differences and $\overline{c}$ is the threshold parameter that will be estimated jointly with the remaining parameters of the dynamic equation[6].

This latter parameter, $\overline{c}$, is very interesting from an economic perspective, because it allows us to assess the behaviour of fuel distributors: in particular, the threshold from which they decide to 'wait and see' before transferring variations in cost to the consumers' price.

The specification presented through equation (3) is the basic approach to specifying asymmetry in a cointegration framework.

With respect to the economic interpretation of the model we will find evidence of long-run asymmetries if we can conclude that the parameters for the error correction term in equation (3), denoted by $\delta^{(1)}$ and $\delta^{(2)}$, are different in statistic terms; analogously, we will find evidence of short-run asymmetries if the parameters that capture the direct effect of shocks in crude-oil price on the retail prices of fuel, denoted by $\gamma^{(1)}$ and $\gamma^{(2)}$, are different in statistic terms.

Furthermore, if the parameters for the regime 1 are larger (in absolute value) than those for the regime two, we can speak of rockets and feathers behaviour.

[6]We could also consider more restricted versions of equation (3) by imposing that certain parameters are the same under both regimes, and only a few of them to change with the regime. We have opted for the most general case by allowing that all the parameters to be different under each regime.

3.3.2 Markov-Switching model

On the other hand, unlike the TAR-ECM approach, Markov-switching methodology assumes that the regime that occurs at time *t* cannot be observed, as it is determined by an unobservable process, which we denote as S_t.[7] This methodology allows us to identify the presence of asymmetries in the formation of diesel or gasoline prices from changes in oil prices agnostically. That is, it does not reveal whether the presence of such asymmetries, if identified, is in line with "rockets and feathers" behaviour or others. The general specification of the model is quite similar to the one formulated in the previous section. Without loss of generality, let the estimated model be:

$$\nabla x_{j,t} = \beta + \sum_{i=1}^{p} \rho_i \nabla x_{j,t-i} + \gamma_0^{(S_t)} \nabla p_{jt} + \sum_{i=1}^{I} \gamma_i^{(S_t)} \nabla x_{j,t-i} + \delta^{(S_t)} \hat{\varepsilon}_{t-1} + \zeta_t \quad (4)$$

$$\zeta_t \underset{iid}{\sim} N\left(0, \sigma_{S_t}^2\right), S_t = \{1,2\}, j = \{diesel, gasoline\}$$

where S_t evolves according to a Markov chain independent from the past observations of ∇x_{jt} and from the present and past observations of ∇p_t and $\hat{\varepsilon}_{t-1}$:

$$Prob\ \{S_t = j | S_{t-1} = i, S_{t-2} = k, \ldots, \nabla p_t, \Omega_{t-1}\} = Prob\{S_t = j | S_{t-1} = i\} = p_{ij},$$

$$Where\ \Omega_{t-1} = \left\{\nabla x_{jt-1,} \nabla x_{jt-2,\ldots,} \nabla p_{t-1,} \nabla p_{t-2\ldots,} \hat{\varepsilon}_{t-1\ldots,} \hat{\varepsilon}_{t-2,\ldots}\right\},$$

where we represent the Markov chain as $\xi_{t+1} = P\xi_t + \nu_{t+1}$, P being the transition matrix, where $p_{ij} = (S_t = j | S_{t-1} = i)$, $j, i = 1,2$, $\nu_{t+1,}$ is a martingale difference sequence, and the *j*th element of ξ_{t+1} (*j*=1,2) being a random variable that takes on the unit value with probability p_{ij} if $S_t=1$, or takes on the zero value otherwise.

Because there are only two possible states of nature, the transition matrix can be defined as:

[7] A more detailed explanation can be found in Chapter 11 of Hamilton (1994).

$$P = \begin{bmatrix} p_{11} & 1-p_{22} \\ 1-p_{11} & p_{22} \end{bmatrix}$$

Let η_t be a 2×1 vector which includes the conditional density functions of ∇x_{jt} for each one of the two different states or regimes:

$$\eta_t = \begin{cases} \frac{1}{\sigma_1\sqrt{2\pi}} exp\left[\frac{-\left(\nabla x_{j,t}-\beta-\sum_{i=1}^{p}\rho_i\nabla x_{j,t-i}-\gamma_0^{(1)}\nabla p_{jt}-\sum_{i=1}^{I}\gamma_i^{(1)}\nabla x_{j,t-i}-\delta^{(1)}\hat{\varepsilon}_{t-1}\right)}{2\sigma_1^2}\right] \\ \frac{1}{\sigma_2\sqrt{2\pi}} exp\left[\frac{-\left(\nabla x_{j,t}-\beta-\sum_{i=1}^{p}\rho_i\nabla x_{j,t-i}-\gamma_0^{(2)}\nabla p_{jt}-\sum_{i=1}^{I}\gamma_i^{(2)}\nabla x_{j,t-i}-\delta^{(2)}\hat{\varepsilon}_{t-1}\right)}{2\sigma_2^2}\right] \end{cases}$$

We also assume that these conditional densities depend only on the current regime S_t and do not depend on the past regimes:

$$f\left(\nabla x_{j,t}|\nabla p_t,\Omega_{t-1},S_t=i;\omega\right)=f\left(\nabla x_{j,t}|\nabla p_t,\Omega_{t-1},S_t=i,S_{t-1}=k,S_{t-2}=l,\dots.;\omega\right) \quad ,$$

for $i,k,l=1{,}2$ and $j=\{gasoline,diesel\}, where$ $\omega=\left\{\beta,\rho_1,\dots,\rho_P,\gamma_0^{(S_t)},\dots,\gamma_I^{(S_t)},\delta^{(S_t)}\right\}$

Let θ be a vector of parameters including ω as well as the probabilities p_{ij}. Our purpose is then to estimate θ based on the past observations in Ω_t.

Given the observed data and knowledge on the population parameter θ, let us assume that $Prob\,\{S_t=j|\Omega_t;\theta\}$ represents the probability that the unobserved regime for observation *t* was regime *j*. These probabilities are collected in vector $\hat{\xi}_{t|t}$:

$$\hat{\xi}_{t|t} = \begin{bmatrix} Prob\,\{S_t=1|\Omega_t;\ \theta\} \\ Prob\,\{S_t=2|\Omega_t;\ \theta\} \end{bmatrix}$$

The probability that the analyst assigns to the possibility that observation *t*+1 was generated by regime *j*, given the data obtained through date *t* is:

$$\hat{\xi}_{t+1|t} = \begin{bmatrix} Prob\,\{S_{t+1}=1|\Omega_t;\ \theta\} \\ Prob\,\{S_{t+1}=2|\Omega_t;\ \theta\} \end{bmatrix}$$

The optimal inference and forecast for each date *t* can be obtained by iterating on these two equations:

$$\hat{\xi}_{t|t} = \frac{\hat{\xi}_{t|t-1}\odot\eta_t}{1_2'(\hat{\xi}_{t|t-1}\odot\eta_t)} \tag{5}$$

$$\hat{\xi}_{t+1|t} = P\hat{\xi}_{t|t} \quad (6)$$

where $1_2' = (1,1)$ and the symbol $\odot$ denotes element by element multiplication.

Given a starting value $\hat{\xi}_{1|0}$ and an assumed value for the population parameter vector θ, one can iterate on (5) and (6) for *t*=1, 2,…,*T*. The log-likelihood function $\mathcal{L}(\theta)$ for the observed data Ω_t, evaluated at the value of θ that was used to perform the iterations, is:

$$\mathcal{L}(\theta) = \sum_{t=1}^{T} log[f(\nabla x_t|\nabla p_t, \Omega_{t-1}; \theta)]$$

$$where\ f(\nabla x_t|\nabla p_t, \Omega_{t-1}; \theta) = 1_2'\left(\hat{\xi}_{t|t-1} \odot \eta_t\right)$$

Once the value of the log likelihood implied by the value of θ has been obtained, such value of θ that maximizes the log likelihood can be found numerically.

On the other hand, the estimated probabilities p_{11} y p_{22} have information about the expected duration of one state or regime. In this case the question is: given that the current regime is *j*, how much will it last? To find the answer, let us define *D* as the duration of state 1; then:

$D = 1, if\ S_t = 1\ and\ S_{t+1} = 2; then, Prob(D = 1) = p_{12} = 1 - p_{11}$

$D = 2, if\ S_t = S_{t+1} = 1\ and\ S_{t+2} = 2; then, Prob(D = 2) = p_{11}p_{12} = p_{11}(1 - p_{11})$

$D = 3, if\ S_t = S_{t+1} = S_{t+2} = 1\ and\ S_{t+3} = 2; then, Prob(D = 3) = p_{11}^2 p_{12} = p_{11}^2(1 - p_{11})$

…..

Then, the expected value of the duration can be estimated as:

$$E(D) = \sum_{i=1}^{\infty} i \cdot \Pr(D = i) = \sum_{i=1}^{\infty} i \cdot p_{11}^{i-1}(1 - p_{11}) = \frac{1-p_{11}}{p_{11}} \sum_{i=1}^{\infty} i \cdot p_{11}^{i} = \frac{1}{1-p_{11}}, \quad (7)$$

for regime 1 and, analogously, the expected duration for regime 2 is $\frac{1}{1-p_{22}}$. (8)

The economic interpretation of this model is as follows: On the one hand, with the test for the hypothesis on the parameter equality of each regime $\left\{\gamma_0^{(S_t)}, \gamma_i^{(S_t)}, \delta^{(S_t)}\right\}, i = 1, \dots I$, we determine the existence of asymmetries in the formation of gasoline and diesel prices both in the short-term (this implies that $\gamma_0^{(S_t=1)} \neq \gamma_0^{(S_t=2)}$, or $\gamma_i^{(S_t=1)} \neq \gamma_i^{(S_t=2)}$ for any $i = 1, \ldots .I$)and/or in the long-term ($\delta^{(S_t=1)} \neq \delta^{(S_t=2)}$). On the other hand, to identify whether these asymmetries are in line with the "rockets and feathers" hypothesis we use the estimated probability assigned by the analyst to the possibility of the observation *t* being generated by regime 1,[8] given the data obtained through $T(\hat{\xi}_{t|T}^{(S_t=1)})$, to estimate the following regression:

$$\hat{\xi}_{t|T}^{(S_{t=1})} = \alpha_0 + \alpha_1 \mu_t \cdot \nabla x_{j,t} + \alpha_2 (1 - \mu_t) \cdot \nabla x_{j,t} + a_{t,} \, a_t \underset{iid}{\sim} N(0, \sigma_a^2),$$

$$\mu_t = \begin{cases} 1, if \;\; \nabla x_{j,t} \geq 0 \\ 0, if \;\; \nabla x_{j,t} \geq 0 \end{cases} \tag{9}$$

If parameter α_1 is statistically different from zero and positive, it means that the dynamic relation corresponding to regime 1 is observed most frequently in periods of positive variations in fuel prices. If the parameter α_2 is statistically different from zero and negative, it means that regime 1 is inversely related to periods of negative variations in fuel prices, or equivalently, regime 2 is directly related to periods of decreases in fuel prices (note that $\hat{\xi}_{t|T}^{(S_t=2)} = 1 - \hat{\xi}_{t|T}^{(S_t=1)}$).

According to this, by contrasting the null hypothesis H_0: $\{\alpha_1 = \alpha_2 = 0\}$ against the alternative H_0: $\{\alpha_1 > 0, \; \alpha_2 < 0\}$, we may conclude that:

i. If we reject the null hypothesis in favour of the alternative one, and the estimated regime 1 values $\gamma_i^{(S_t=1)}$, $i = 0,1, \ldots .I$ are statistically greater than those of regime 2, we conclude that, in the short-run, the regimes identified in regression (4) suggest asymmetries in line with "rockets and feathers" behaviour. This is because when retail prices tend to increase, the economy is most probably placed in regime 1, characterized by a stronger short-run transfer of oil price shocks towards gasoline, or diesel, prices (rockets behaviour);
ii. If we reject the null hypothesis in favour of the alternative one, and the estimated regime 1 values $\delta^{(S_t=1)}$, are statistically greater than those of regime 2 (in absolute value), we conclude that, in the long-run, the regimes identified in

[8] Given the presence of only two regimes, we choose regime 1 without loss of generality.

regression (4) are in line with “rockets and feathers” behaviour. This is because when retail prices tend to increase, the economy is most probably placed in regime 1, characterized by a faster convergence towards the long-run equilibrium, summarized as having a stronger long-run effect of oil price shocks towards gasoline, or diesel, prices (rockets behaviour);

iii. If we reject the null hypothesis in favour of the alternative one, and the estimated regime 1 values $\gamma_i^{(S_t=1)}, i = 0,1, \dots . I$, are statistically lower than those of regime 2, we conclude that, in the short-run, the regimes identified in regression (4) suggest asymmetries which are not in line with “rockets and feathers” behaviour. This is because when retail prices tend to increase, the economy is most probably placed in regime 1; but in this case such a regime would correspond to a milder short-run transfer of oil price shocks towards gasoline, or diesel, prices;

iv. If we reject the null hypothesis in favour of the alternative one, and the estimated regime 1 values $\delta^{(S_t=1)}$, are statistically lower (in absolute value) than those of regime 2, we conclude that, in the long-run, the regimes identified in regression (4) reflect asymmetries which are not in line with “rockets and feathers” behaviour. This is because when retail prices tend to increase, the economy is most probably placed in regime 1; but in this case, this regime would correspond to a slower convergence towards the long-run equilibrium, summarized as having a softer long-run effect of oil price shocks towards gasoline, or diesel, prices;

v. If we cannot reject the null hypothesis, regression (4) identifies asymmetries but we cannot determine whether they are in line with “rockets and feathers” behaviour or inversely, because the probability of being in regime 1 would not be regularly linked to inflationary or deflationary processes for fuel prices in this case.

In the last v) case, regression 4 could be detecting asymmetric behaviour in gasoline or diesel prices according to periods of high and low volatility (in line with the work of Boroumand et al. (2016)). However, we have explored this possibility by estimating a regression as (4) under the assumption that the Markov chain governing the states of the regression parameters $\left\{\gamma_i^{(S_{1,t})}, \delta^{(S_{1,t})}\right\}$ is distinct and independent from that governing the behaviour of the variance $\left(\sigma^2_{S_{2,t}}\right)$. Our results do not suggest that different volatility patterns are the driving force behind the asymmetry detected in the parameters for the selected countries throughout the sample period.[9]

4. Empirical results

In this section we present our empirical findings from the estimation of TAR-ECM and Switching-Markov models. We test two types of petroleum energy products: gasoline and diesel fuel. The two oil products constitute the most important petroleum derivatives sold in Europe. The estimated coefficients are reported in tables 4 and 5 and t-statistics are reported in tables 6.

4.1 TAR-ECM estimations

We have specified and estimated five different TAR-ECM models according to the number of lags of the endogenous and exogenous variables (ranging from one to three lags) for Germany, United Kingdom, France and Italy.

AIC and BIC tests joint with R^2 seem to indicate that the most desirable models are the simplest ones, with one lag for the endogenous variable and two terms for the exogenous variable, corresponding to the contemporaneous effect and the effect after one week of the shock in the oil price. In terms of the model described in equation (3), the selected model corresponds to the case p=q=1. The estimation results of this model appear in table 4 (4.a, 4.b, 4.c, 4.d, 4.e, 4.f, 4.g, and 4.h) corresponding to the case of gasoline and diesel fuel for the four countries under study.

Table 6 (6.a, 6.b, 6.c. and 6.d) includes the tests carried out to check whether the parameters corresponding to one regime are statistically different to the homologous parameter of the other regime. We will use these results throughout the following discussion.

[9] This analysis is available upon request.

The main findings are:

a) In relation with the gasoline market, despite the fact that we estimate non-zero threshold values which are statistically significant according to the likelihood ratio criteria, and consistently placed around -2% for the four economies, we do not find strong enough evidence of asymmetric short-run and long-run effects from crude oil price shocks towards the retail price for any of the four countries analyzed: the contemporaneous and delayed effect are statistically alike under both regimes because we cannot reject the hypothesis that $\gamma_0^{(1)} \approx \gamma_0^{(2)}$ and $\gamma_1^{(1)} \approx \gamma_1^{(2)}$ when we carry out a test of statistical significance. In this sense, we also find evidence of similar speed of adjustment towards long-run equilibrium: $\delta^{(1)} \approx \delta^{(2)}$ in all cases (see the first column of tables 6.a to 6.d). This result is different from the results of the study by Galeotti, Lanza and Manera (2003), who find evidence of asymmetries. The reason behind this difference could be that these authors estimate an ECM with a zero threshold while in our case the estimated endogenous threshold is different from zero for the four countries. Our results are also different from those of Grasso and Manera (2007), who find mixed evidence depending on the country and the stage (wholesale, retail or single).

[Insert table 4.a, 4.c, 4.e, 4.g and 6's]

b) Concerning the diesel market:

b.1) The results suggest the existence of asymmetries in the short-run for Germany, France and Italy; but they are not in line with the "rockets and feathers behaviour" in any of these cases. In fact, the results suggest a pattern opposite to 'rockets-feathers'. The contemporaneous effect from oil to retail prices is stronger under the second regime, which corresponds to the variation of prices below the threshold, while the delayed effects are statistically similar under both regimes. More precisely, in terms of the model we find that $\gamma_0^{(1)} < \gamma_0^{(2)}$ and $\gamma_1^{(1)} \approx \gamma_1^{(2)}$. On the other hand, for the United Kingdom the estimations do not support any evidence of asymmetry regarding the short-run transmission from oil to retail prices, so we cannot reject the hypothesis that both the contemporaneous and the delayed effects are similar under both regimes. (See the second column of tables 6.a to 6.d)

b.2) However, concerning the coefficients for the error correction term which capture the adjustment speed towards the long-run equilibrium, we find evidence of asymmetries with a faster adjustment in regime 1: $\delta^{(1)} > \delta^{(2)}$ for all the countries except Germany. So, the results corresponding to the long-run asymmetries fall in line with the rockets-feathers hypothesis.

[Insert table 4.b, 4.d, 4.f, 4.h and 6.a to 6.d]

c) The negative value obtained for the coefficients of the error correction term, $\delta^{(1)}$ and $\delta^{(2)}$, has also been found for other countries[10]; its statistic significance means that the ECM mechanism is working to bring the system back to the equilibrium.

d) Finally, in the four cases, we not only obtain negative estimated values for the threshold variation rate for the gasoline market (consistently around -2%) but also do so for the diesel market (between -2% and -4%). The confidence intervals of these parameter estimations are obtained by inverting the likelihood ratio test-statistic (see Figures 1 and 2)[11], confirming that the zero value is out of the confidence interval. Hence, the results suggest that the frequently used

[10]For example Bermingham and O'Brien (2011).

[11]Following Hansen (1997) we construct these confidence intervals inverting the likelihood ratio test-statistic to test the hypothesis that the threshold is equal to some specific value c_0, given by

$$LR(c_0) = n\left(\frac{\hat{\sigma}^2(c_0) - \hat{\sigma}^2(\hat{c})}{\hat{\sigma}^2(\hat{c})}\right)$$

Notice that $LR(c_0)=0$. The 100xα% confidence interval the threshold is given by the set $\hat{C}_\alpha$ consisting of those values of c for which the null hypothesis is not rejected at significance level α. That is:

$$\hat{C}_\alpha = \{c: LR(c) \leq z(\alpha)\},$$

where $z(\alpha)$ is the 100xα percentile of the asymptotic distribution of the *LR*-statistic. These percentiles are given in Hansen (1997, table 1) for various values of α. The set $\hat{C}_\alpha$ provides a valid confidence region as the probability that the true threshold value is contained in $\hat{C}_\alpha$ approaches α and the simple size n becomes large. A graphical method used to obtain the region $\hat{C}_\alpha$ is plotted in the *LR*-statistic represented in Figures 1 and 2.

exogenous assumption of a zero threshold might not be an adequate assumption, at least for these countries and this sample. This result contrasts with the one found by Grasso and Manera (2007), who find positive, null or negative values for the threshold in the gasoline market depending on the country.

[Insert Figures 1 and 2]

In sum, we conclude that no evidence of price asymmetry in the short-run as well as in respect to the adjustment speed towards long-run equilibrium is obtained using the TAR-ECM methodology for the gasoline market.

Quite the contrary, in the diesel market we find evidence of asymmetries both in the short-run and in the long-run behaviour. First, with respect to the short-run transmission of oil shocks we find no asymmetries for the United Kingdom and we find asymmetries opposite to the rockets and feathers hypothesis for Germany, France and Italy. Second, with respect to the speed of adjustment towards the long-run equilibrium, we find no asymmetry in the case of Germany and asymmetries in line with the rockets-feathers behaviour in the case of France, Italy and the United Kingdom.

4.2 Markov-Switching estimations

In this section we adopt a more sophisticated econometric model. To the best of our knowledge, this type of model has never been used in any European country to estimate asymmetric response parameters of fuel retail prices to oil price shocks (the only work using Markov-switching within this framework is Boroumand et al 2016, who use this methodology to split the sample into periods of low and high volatility, but they obtain the parameter asymmetries under the zero threshold methodology). It therefore introduces a further improvement to the methodology. In particular, this methodology is capable of working efficiently in samples that include structural breaks, as is the case with oil and fuel prices. The estimation results of this methodology appear in table 5 (5.a, 5.b, 5.c, 5.d, 5.e, 5.f, 5.g, and 5.h)

The results arising from this methodology are quite different to the ones arising from the TAR-ECM methodology, and they suggest the existence of asymmetries that are undetected using less flexible models.

4.2.1 <u>Gasoline market</u>

Starting with the gasoline market, the switching methodology finds evidence of short-run asymmetries (captured by the $\gamma's$ coefficients) for United Kingdom, France and Italy; by the contrary, the TAR-ECM method did not find any. Furthermore, the asymmetries fall in line with the rockets-feathers, according to the interpretation explained above, based on the estimation of equation (9) (see table 7).

The case for Germany is somewhat more complex. We find asymmetries but they are inconclusive: the contemporaneous effect is stronger for the second regime, $\gamma_0^{(1)} < \gamma_0^{(2)}$, while the one-week delayed effect is stronger under the first regime, $\gamma_1^{(1)} > \gamma_1^{(2)}$. This asymmetry cannot be directly interpreted as being in line with the rockets and feathers hypothesis. So we developed further analysis. In particular, we simulated the dynamic response exhibited by the variation rate of gasoline retail prices consequent to an increase in the price of crude oil conditioned on the assumption that the economy is placed in one particular regime. That is, we first simulated the part of the switching markov model corresponding to the case $S_t = 1$ and then simulated the second part corresponding to the case $S_t = 2$ (see Figure 3 for a summary of the results). The aim of this exercise is to gather all the effects resulting from the mixture of the auto-regressive behaviour of retail prices, the direct short-run effects of crude oil shocks and the error correction model working to restore the long-run equilibrium.

Figure 3.a plots the response in period *t* of the gasoline price variation rate during the first two months (*t* = 0,…,8) after an increase in crude oil price equal to one standard deviation[12]. In figure 3.b we display the accumulated response from the period when the shock occurred until the period *t*. We can observe that, although the instantaneous effect is stronger under the second regime, the delayed effect and the

[12] In the simulation we have assumed that, prior to the shock, the system is placed in the long-run equilibrium ($\hat{\varepsilon}_{-1} = 0$) and we have normalized to 1 the price of oil prior to the shock ($p_{-1} = 1$).

dynamics of the error correction model lead to a stronger accumulated effect for the first regime over the course of two months after the shock. As a consequence, the results suggest that the gasoline market matches the rockets-feathers behaviour reasonably well.

[Insert Figure 3]

Regarding the long-run responses, the switching methodology also captures asymmetries in line with the rockets-feathers behaviour for all the countries (Germany, UK, France and Italy), as opposed to the TAR-ECM model which found no asymmetries. More precisely, in terms of the estimated coefficients with the Markov-switching method, the statistic tests conclude that the coefficients for the error correction term are significantly larger in absolute value under the first regime, $\delta^{(1)} > \delta^{(2)}$ (see the third column in table 6). Furthermore, the asymmetries detected for the long-run are in line with the rockets and feathers hypothesis (see table 7).

The switching methodology also provides some additional information which is unavailable using the TAR-ECM method: in particular, the volatility of the noise term for each regime ($\sigma^2_{S_t}$, for S_t =1,2) and the probability of staying in one given regime for two consecutive periods in each regime (p_{11} for the first regime, and p_{22} for the second). If we take a look at the estimations, the results suggest that the noise term is more volatile in regime 1 for all the cases, that is, in statistical terms, $\sigma^2_{(1)} > \sigma^2_{(2)}$. Furthermore, in the case of UK the probability of staying in one given regime for two consecutive periods is similar in statistical terms for regimes 1 and 2, that is, $p_{11} \approx p_{22}$. We find the same result for Germany, while in the case of Italy it is larger for the first regime, $p_{11} > p_{22}$ (the first regime corresponds to the more frequent and persistent upward trends in fuel prices within the sample).

As an additional interpretation of the results, it is possible to analyze the expected duration of each regime, i.e., the expected length the system in state j, which can be calculated from the transition probabilities p_{11} and p_{22}, according to (7) and (8). In this sense, it is possible to infer an average duration, depending on the country, between 3 and 15 weeks for the first regime (associated to the upward trend in crude oil price) in the sample, while the average duration of the second regime is between 2 and 15 weeks.

4.2.2 Diesel market

In terms of the diesel market and starting with the long-run asymmetries, the Markov-switching methodology points to the same conclusions as the TAR-ECM model. Specifically, evidence suggests that the response of retail prices to shocks in crude oil prices is stronger under the first-regime for UK, France and Italy. These asymmetries, according to the results in table 7, match the rockets-feathers behaviour. However, the response is similar under both regimes in the case of Germany; so no evidence of long-run asymmetry is found for this country.

Regarding the short-run asymmetries response, the results are also generally in line with the TAR-ECM methodology. However, the switching methodology suggests that the short-run asymmetries are in line with the rockets-feathers hypothesis for Italy, as opposed to the conclusion obtained with TAR-ECM (see table 7). Finally, in the case of Germany the method finds asymmetric responses, both contemporaneous and delayed. However they are inconclusive, as were the results for the gasoline market: the contemporaneous response is stronger in the second regime, and the delayed response is stronger in the first regime. We once again carry out the simulation exercise developed in the gasoline market (section 3.2.1.). Figure 4 shows the results. However, in this case, the exercise sheds no light. Based on the accumulated response (figure 4.b), we do not obtain clear evidence of asymmetries in the dynamic response of gasoil: the instantaneous effect is stronger under the second regime, whilst the one-week delayed effect is stronger under the first regime and the difference is not significant from a statistic point of view for the following periods. So, it does not match the rockets-feathers pattern.

[Insert Figures 3 and 4]

The results suggest that the noise term is more volatile in regime 1 for all the cases. Furthermore, like in the gasoline market, the probability of staying in one given regime for two consecutive periods is statistically different in the case of the Italian market, being larger for the first regime ($p_{11} > p_{22}$). On the contrary, the probability of staying in one given regime for two consecutive periods is similar in statistic terms ($p_{11} \approx p_{22}$) for U.K, Germany and France.

As in the gasoline case, it is possible to analyze the expected duration of each regime. In this sense, using a 95% significance test it is possible to infer an average duration between 11 and 13 weeks for the first regime (associated to the upward trend in crude oil price) in the case of France and Italy and at least around 25 weeks in Germany and U.K, while the average duration of the second regime is 2 for Italy and France and the same as the previous case, 25 for Germany and U.K..

Finally, table 8 allows the reader to verify whether asymmetries are present in the four economies analyzed in this paper.

[Insert Table 8]

Overall, in section 4 we find that the flexibility of the Markov-switching methodology allows us to obtain evidence of asymmetries in line with the rockets-feathers hypothesis for the gasoline market for these countries, improving on the results obtained under the TAR-ECM approach. With respect to the diesel market, albeit to a lesser extent, some gain is also obtained by using the Markov-switching framework.

5. Conclusions

Numerous studies on oil pricing asymmetries, forming part of the so-called "rockets and feathers" behaviour, examine whether retail prices rise faster than they fall in response to changing oil prices. Thus, as Bermingan and O'Brien (2011) point out, the balance of evidence recently tends to support the conclusion claiming that no significant pricing asymmetries are present in the Euro-area petrol and diesel markets, at least. Also in this line, ECB (2010) reaffirms that there are no significant asymmetries in petrol and diesel markets in the Euro-area.

In this paper we analyze the potential asymmetric response of gasoline and diesel retail prices to changes in oil prices for the four main European economies (Germany, United Kingdom, France and Italy) and its relation with the so-called ‘rockets and feathers’ behaviour. Previous works have analyzed the different causality channels depending on the negative or positive sign of the variation rate for the oil price. That is, the previous analysis set the periods corresponding to increases in the price of oil apart from the periods with decreases in the price of oil. We use a different approach, a Threshold Auto-regressive Error Correction Model, to endogenously estimate the threshold in the variation rate of the price of oil that marks the difference. In a second stage, we test the robustness of the results by using a more sophisticated econometric methodology, a Markov-switching approach. This type of model has never been used to estimate regime-switching parameters for Europe, so it introduces further improvement to the methodology used to date.

Using the TAR-ECM methodology, we find no evidence of an asymmetric response of gasoline prices to changes in the price of crude oil, neither in the short-run or in the adjustment towards the long-run equilibrium. In the case of diesel fuel we find evidence of asymmetries in the short-run for Germany, France and Italy. However, the asymmetries found are opposite to rockets-feathers hypothesis. In the long-run our estimations reveal the presence of asymmetries in the diesel market for all the economies, except for Germany, and these asymmetries are in line with the “rockets and feathers” behaviour.

The results arising from the Markov-Switching methodology are quite different to the ones arising from the TAR-ECM methodology. In particular, the Markov-Switching method allows us to obtain asymmetries in line with the rockets and feathers in the gasoline market, both in the short and in the long-run for all the countries analyzed, as a major difference with the null evidence of asymmetry under the TAR-ECM.

With respect to the diesel market, the Markov-Switching approach is also able to detect asymmetries found under the TAR-ECM method, although in this market the conclusions are more case by case than in the gasoline market. For UK, France and Italy, the Markov-switching result confirms the evidence that these asymmetries are in line with rockets and feathers behaviour in the long-run, results found by the TAR-ECM model. Additionally, this methodology finds a rockets-feathers pattern in the short-run for the case of Italy, which the TAR-ECM did not find

In sum, based on the results obtained in this study we find that more sophisticated and flexible methodologies like Switching-Markov are capable of detecting asymmetries in cases where the classical models are incapable of doing so. Furthermore, they may also determine whether these asymmetries are in line with the rockets and feathers hypothesis. In many cases, this is also something that the traditional models are incapable of doing.

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Table 1. Unit root test

		ADF test	Phillips-Perron test	Kwiatkowski-Phillips-Schmidt-Shin test	Structural breaks-Perron test
		Null Hypothesis: x has a unit root	Null Hypothesis: x has a unit root	Null Hypothesis: x is stationary	Null Hypothesis: x has a unit root
Gasoline price	France	-2.684	-2.871	1.800	-4.413
	Germany	-2.564	-2.576	1.751	-4.352
	Italy	-2.665	-2.413	1.755	-4.230
	United Kingdom	-2.861	-2.393	1.429	-4.824
Gasoil price	France	-2.177	-2.043	1.440	-4.082
	Germany	-2.054	-1.965	1.567	-4.277
	Italy	-2.044	-1.915	1.400	-3.950
	United Kingdom	-2.033	-2.118	1.383	-4.578
Oil crude forward price		-2.774	-2.783	1.645	-4.499
Test critical values					
1% level		-3.445	-3.445	0.739	-5.920
5% level		-2.868	-2.868	0.463	-5.230
10% level		-2.570	-2.570	0.347	-4.920

Table 2. Granger Causality test

		France	Germany	Italy	United Kingdom
		χ^2 (p-value)	χ^2 (p-value)	χ^2 (p-value)	χ^2 (p-value)
Gasoline Price vs. Crude oil price	Dependent variable: Gasoline	231.470 (0.000)	137.800 (0.000)	139.227 (0.000)	160.502 (0.000)
	Dependent variable: Crude oil	19.483 (0.0125)	12.971 (0.113)	24.845 (0.002)	11.303 (0.185)
Gasoil Price vs. Crude oil price	Dependent variable: Gasoil	362.117 (0.000)	166.203 (0.000)	179.777 (0.000)	183.322 (0.000)
	Dependent variable: Crude oil	9.843 (0.276)	6.502 (0.591)	18.828 (0.016)	11.593 (0.170)

Note: Eight lags have been used.

Table 3. Results of bounds F-test for cointegration using the critical value bounds from Pesaran et al. (2001)

	France	Germany	Italy	U.K
$F_{gasoil}(2,T\text{-}(3+I+J))=$	6.003	8.618	7.519	7.119
$F_{gasoline}(2, T\text{-}(3+I+J))=$	10.154	8.547	7.218	9.375
	Lower bound I(0)		Upper bound I(1)	
Significance at 1% level	6.84		7.84	
Significance at 5% level	4.94		5.73	
Significance at 10% level	4.04		4.78	

GERMANY

Table 4.a: Gasoline-Oil TAR-ECM Models

	Parameters	Regime 1	Regime 2
	β	0.0035 (.0034)	**-0.0139(.0056)**
	ρ	**-0.3404 (.0633)**	**-0.2099 (.0605)**
	γ_0	**0.3422(.0693)**	**0.3789 (.0727)**
	γ_1	**0.5777(.0664)**	**0.6554(.0816)**
	δ	**-0.1652(.0549)**	**-0.2723 (.0650)**
Threshold	$\bar{c}$	-0.0181 [-0.0288,-0.0088]*	
	AIC test BIC test	452.33 -2.78*10^3	

Table 4.b: Diesel-Oil TAR-ECM Models

	Parameters	Regime 1	Regime 2
	β	0.0039 (.0022)	-0.0042(.0054)
	ρ	**-0.3411 (.0563)**	**-0.4594(.0619)**
	γ_0	**0.2034 (.0499)**	**0.4507(.0619)**
	γ_1	**0.4370 (.0502)**	**0.4807 (.0684)**
	δ	**-0.2719 (.0455)**	**-0.2743 (.0919)**
Threshold	$\bar{c}$	-0.0221 [-0.0291,-0.0190]*	
	AIC test BIC test	451.84 -2.99*10^3	

Table 5.a: Gasoline-Oil Markov-Switching Models

	Parameters	Regime 1	Regime 2
Non regimen Switching	β	0.0009 (.0018)	0.0009 (.0018)
	ρ	**-0.2859 (.0453)**	**-0.2859 (.0453)**
	γ_0	0.1878 (.2467)	**0.4119(.0638)**
	γ_1	**1.1066 (.3214)**	**0.5043(.0566)**
	δ	**-0.3258(.1213)**	**-0.0881 (.0295)**
	σ^2	**0.0628 (.0096)**	**0.0301 (.0021)**
	p_{ii}	**0.6594 (.2019)**	**0.9339 (.0384)**

Table 5.b: Diesel-Oil Markov-SwitchingModels

	Parameters	Regime 1	Regime 2
Non regimen Switching	β	-0.0000 (.0014)	-0.0000 (.0014)
	ρ	**-0.3687 (.0474)**	**-0.3687 (.0474)**
	γ_0	**0.2126(.0589)**	**0.6145(.0649)**
	γ_1	**0.5134(.0491)**	**0.2643(.1047)**
	δ	**-0.2215 (.0384)**	**-0.1832 (.0750)**
	σ^2	**0.0327 (.0015)**	**0.0208 (.0023)**
	p_{ii}	**0.9864 (.0119)**	**0.9682 (.0230)**

Table 6.a: Short-run Asymmetries and asymmetric Adjustment Speeds

	TAR-ECM		Switching-Markov	
	Gasoline	Diesel	Gasoline	Diesel
Test	t-Statistic	t-Statistic	t-Statistic	t-Statistic
$H_0: \gamma_0^{(1)} = \gamma_0^{(2)}$ $H_1: \gamma_0^{(1)} \neq \gamma_0^{(2)}$	0.3648	3.1714***	0.8188	4.6678***
$H_0: \gamma_1^{(1)} = \gamma_1^{(2)}$ $H_1: \gamma_1^{(1)} \neq \gamma_1^{(2)}$	0.7388	0.6870	1.8886*	2.1085**
$H_0: \delta^{(1)} = \delta^{(1)}$ $H_1: \delta^{(1)} \neq \delta^{(1)}$	1.2581	0.0118	1.9322*	0.4101
$H_0: p_{11} = p_{22}$ $H_1: p_{11} \neq p_{22}$			1.4345	0.9053
			F-Statistic	F-statistic
$H_0: \sigma^{(1)} = \sigma^{(2)}$ $H_1: \sigma^{(1)} \neq \sigma^{(2)}$			2.0897***	1.5748***

A single (double, triple) asterisk denotes significance at 10% (5%, 1%) level

UNITED KINGDOM

Table 4.c: Gasoline-Oil TAR-ECM Models:

	Parameters	Regime 1	Regime 2
	β	0.0013 (.0014)	0.0013 (.0014)
	ρ	**0.3165 (.0413)**	**0.3165 (.0413)**
	γ_0	**0.1322(.0356)**	**0.1362 (.0380)**
	γ_1	**0.1771(.0338)**	**0.2099(.0400)**
	δ	**-0.1118(.0259)**	**-0.0808 (.0248)**
Threshold	$\bar{c}$	-0.0197 [-0.0221,-0.0188]*	
	AIC test BIC test	447.02 $-3.36*10^3$	

Table 4.d: Diesel-Oil TAR-ECM Models:

	Parameters	Regime 1	Regime 2
	β	**0.0076 (.0012)**	-0.0035(.0030)
	ρ	0.0541 (.0516)	**0.2181(.0776)**
	γ_0	**0.0574 (.0253)**	**0.1074(.0372)**
	γ_1	**0.1580 (.0250)**	**0.1571 (.0374)**
	δ	**-0.2936 (.0253)**	**-0.1097 (.0355)**
Threshold	$\bar{c}$	-0.0253 [-0.0290,-0.0230]*	
	AIC test BIC test	450.58 $-3.55*10^3$	

Table 5.c: Gasoline-Oil Markov-Switching Models:

	Parameters	Regime 1	Regime 2
Non regimen switching	β	0.0002 (.0009)	0.0002 (.0009)
	ρ	**0.2669 (.0360)**	**0.2669 (.0360)**
	γ_0	**0.1309(.0391)**	**0.1345(.0298)**
	γ_1	**0.2598(.0406)**	**0.0614(.0296)**
	δ	**-0.1665(.0259)**	0.0105 (.0164)
	σ^2	**0.0233 (.0014)**	**0.0071 (.0018)**
	p_{ii}	**0.6677 (.0738)**	**0.4073 (.1761)**

Table 5.d: Diesel-Oil Markov-Switching Models:

	Parameters	Regime 1	Regime 2
Non regimen switching	β	0.0010 (.0007)	0.0010 (.0007)
	ρ	**0.1906 (.0463)**	**0.1906 (.0463)**
	γ_0	-0.1055 (.1220)	**0.1114(.0239)**
	γ_1	0.0642(.1050)	**0.1630(.0276)**
	δ	**-0.2763 (.0713)**	**-0.0979(.0164)**
	σ^2	**0.0341 (.0069)**	**0.0139 (.0009)**
	p_{ii}	**0.8601 (.0846)**	**0.9876 (.0134)**

Table 6.b: Short-run Asymmetries and asymmetric Adjustment Speeds

	TAR-ECM			Switching-Markov	
	Gasoline	Diesel		Gasoline	Diesel
Test	t-Statistic	t-Statistic		t-Statistic	t-Statistic
$H_0: \gamma_0^{(1)} = \gamma_0^{(2)}$ $H_1: \gamma_0^{(1)} \neq \gamma_0^{(2)}$	0.0770	1.111		0.0657	1.7602
$H_0: \gamma_1^{(1)} = \gamma_1^{(2)}$ $H_1: \gamma_1^{(1)} \neq \gamma_1^{(2)}$	0.6347	0.0204		3.9623***	0.9046
$H_0: \delta^{(1)} = \delta^{(1)}$ $H_1: \delta^{(1)} \neq \delta^{(1)}$	0.7547	4.2222***		6.6185***	2.5720***
$H_0: p_{11} = p_{22}$ $H_1: p_{11} \neq p_{22}$				1.3297	1.6197
				F-Statistic	F-statistic
$H_0: \sigma^{(1)} = \sigma^{(2)}$ $H_1: \sigma^{(1)} \neq \sigma^{(2)}$				3.3014***	2.4588***

A single (double, triple) asterisk denotes significance at 10% (5%, 1%) level

FRANCE

Table 4.e: Gasoline-Oil TAR-ECM Models:

	Parameters	Regime 1	Regime 2
	β	0.0013 (.0016)	-0.0059 (.0050)
	ρ	**0.1943 (.0557)**	-0.0291(.0574)
	γ_0	**0.1816(.0356)**	**0.1917(.0529)**
	γ_1	**0.4410(.0349)**	**0.5023(.0613)**
	δ	**-0.1139(.0363)**	**-0.2105(.0654)**
Threshold	$\bar{c}$	-0.0243 [-0.0330,-0.0198]*	
	AIC test BIC test	451.26 $-3.25*10^3$	

Table 4.f: Diesel-Oil TAR-ECM Models:

	Parameters	Regime 1	Regime 2
	β	**0.0019 (.0009)**	**0.0019 (.0009)**
	ρ	0.0406 (.0391)	0.0406 (.0391)
	γ_0	**0.1173 (.0233)**	**0.2179(.0498)**
	γ_1	**0.3911(.0234)**	**0.4280(.0508)**
	δ	**-0.1668 (.0233)**	-0.0410 (.0279)
Threshold	$\bar{c}$	-0.0400 [-0.0469,-0.0340]*	
	AIC test BIC test	446.61 $-3.54*10^3$	

Table 5.e: Gasoline-Oil Markov-Switching Models:

	Parameters	Regime 1	Regime 2
Non regimen switching	β	-0.0008 (.0008)	-0.0008 (.0008)
	ρ	**0.1216 (.0360)**	**0.1216 (.0360)**
	γ_0	**0.3722(.1122)**	**0.1325 (.0236)**
	γ_1	**0.6835(.1372)**	**0.3794 (.0277)**
	δ	**-0.3137(.0852)**	**-0.0452(.0160)**
	σ^2	**0.0395 (.0040)**	**0.0130 (.0009)**
	p_{ii}	**0.6073 (.1179)**	**0.8878 (.0306)**

Table 5.f: Diesel-Oil Markov-Switching Models:

	Parameters	Regime 1	Regime 2
Non regimen switching	β	-0.0001 (.0007)	-0.0001 (.0007)
	ρ	**0.0910 (.0389)**	**0.0910 (.0389)**
	γ_0	**0.1926(.0394)**	**0.1873 (.0312)**
	γ_1	**0.3785 (.0365)**	**0.4692 (.0245)**
	δ	**-0.1761 (.0308)**	**-0.0853(.0251)**
	σ^2	**0.0216 (.0008)**	**0.0071 (.0007)**
	p_{ii}	**0.6944 (.0771)**	**0.4997 (.0688)**

Table 6.c: Short-run Asymmetries and asymmetric Adjustment Speeds

	TAR-ECM			Switching-Markov	
	Gasoline	Diesel		Gasoline	Diesel
Test	t-Statistic	t-Statistic		t-Statistic	t-Statistic
$H_0: \gamma_0^{(1)} = \gamma_0^{(2)}$ $H_1: \gamma_0^{(1)} \neq \gamma_0^{(2)}$	0.1573	1.8277*		2.0603**	0.0916
$H_0: \gamma_1^{(1)} = \gamma_1^{(2)}$ $H_1: \gamma_1^{(1)} \approx \gamma_1^{(2)}$	1.2931	0.6678		2.0669**	1.9417*
$H_0: \delta^{(1)} = \delta^{(1)}$ $H_1: \delta^{(1)} \neq \delta^{(1)}$	1.2919	7.1587***		3.0557***	2.0339*
$H_0: p_{11} = p_{22}$ $H_1: p_{11} \neq p_{22}$				2.5350***	3.8159***
				F-Statistic	F-statistic
$H_0: \sigma^{(1)} = \sigma^{(2)}$ $H_1: \sigma^{(1)} \neq \sigma^{(2)}$				3.0341***	3.0161***

A single (double, triple) asterisk denotes significance at 10% (5%, 1%) level

ITALY

Table 4.g: Gasoline-Oil TAR-ECM Models:

	Parameters	Regime 1	Regime 2
	β	**0.0026 (.0013)**	**-0.0077 (.0034)**
	ρ	**0.1796 (.0561)**	**0.1234 (.0583)**
	γ_0	**0.1624(.0284)**	**0.1976(.0403)**
	γ_1	**0.3190(.0290)**	**0.2463(.0430)**
	δ	**-0.1525(.0334)**	**-0.2256 (.0620)**
Threshold	$\bar{c}$	-0.0199 [-0.0238,-0.0178]*	
	AIC test BIC test	449.77 $-3.46*10^3$	

Table 4.h: Diesel-Oil TAR-ECM Models:

	Parameters	Regime 1	Regime 2
	β	**0.0029 (.0009)**	**0.0029 (.0009)**
	ρ	0.0573 (.0418)	0.0573 (.0418)
	γ_0	**0.1251(0.0216)**	**0.2190 (.0376)**
	γ_1	**0.2560(0.0213)**	**0.2528 (.0428)**
	δ	**-0.1964 (0.0229)**	**-0.0086(.0269)**
Threshold	$\bar{c}$	-0.0344 [-0.0373,-0.0313]*	
	AIC test BIC test	445.37 $-3.64*10^3$	

Table 5.g: Gasoline-Oil Markov-Switching Models:

	Parameters	Regime 1	Regime 2
Non regimen switching	β	-0.0002 (.0003)	-0.0002 (.0003)
	ρ	**0.0638 (.0140)**	**0.0638 (.0140)**
	γ_0	**0.2172(.0301)**	-0.0011 (.0085)
	γ_1	**0.3846(.0306)**	**0.0424 (.0082)**
	δ	**-0.1665(.0249)**	-0.0028 (.0064)
	σ^2	**0.0198 (.0008)**	**0.0024 (.0003)**
	p_{ii}	**0.8186 (.0343)**	**0.5284 (.0637)**

Table 5.h: Diesel-Oil Markov-Switching Models:

	Parameters	Regime 1	Regime 2
Non regimen switching	β	**0.0002 (.0001)**	**0.0002 (.0001)**
	ρ	**0.0114 (.0039)**	**0.0114 (.0039)**
	γ_0	**0.1678 (.0218)**	-0.0028 (.0025)
	γ_1	**0.2880 (.0217)**	**0.0121(.0020)**
	δ	**-0.1237(.0174)**	**-0.0070 (.0018)**
	σ^2	**0.0157 (.0006)**	**0.0005 (.0001)**
	p_{ii}	**0.9044 (.0197)**	**0.4620 (.0683)**

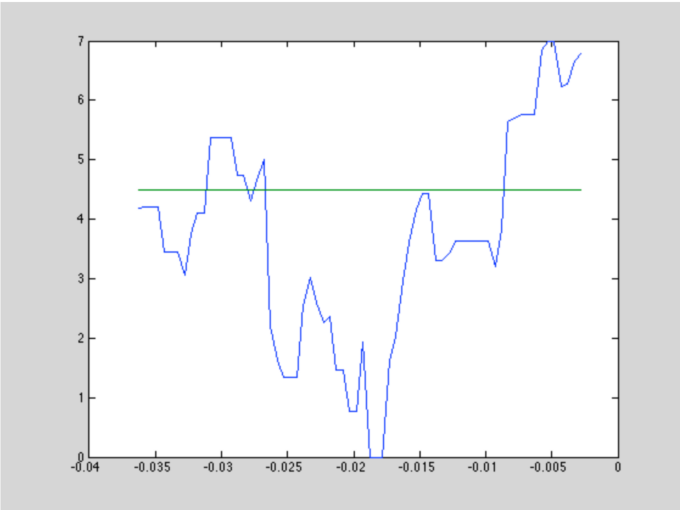
Table 6.d: Short-run Asymmetries and asymmetric Adjustment Speeds

	TAR-ECM			Switching-Markov	
	Gasoline	Diesel		Gasoline	Diesel
Test	t-Statistic	t-Statistic		t-Statistic	t-Statistic
$H_0: \gamma_0^{(1)} = \gamma_0^{(2)}$ $H_1: \gamma_0^{(1)} \neq \gamma_0^{(2)}$	0.7121	2.1637**		6.8817***	7.7738***
$H_0: \gamma_1^{(1)} = \gamma_1^{(2)}$ $H_1: \gamma_1^{(1)} \approx \gamma_1^{(2)}$	1.4021	0.0685		10.8049***	12.6673***
$H_0: \delta^{(1)} = \delta^{(1)}$ $H_1: \delta^{(1)} \neq \delta^{(1)}$	1.0374	8.5764***		6.3291***	6.7026***
$H_0: p_{11} = p_{22}$ $H_1: p_{11} \neq p_{22}$				4.7011***	6.6117***
				F-Statistic	F-statistic
$H_0: \sigma^{(1)} = \sigma^{(2)}$ $H_1: \sigma^{(1)} \neq \sigma^{(2)}$				8.1764***	31.3583***

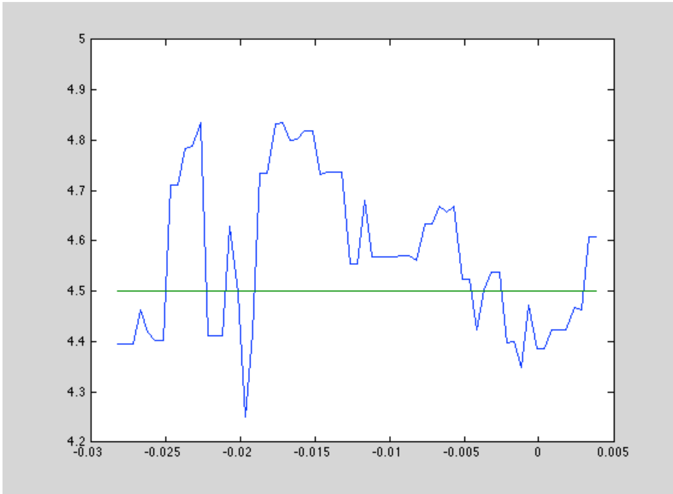
A single (double, triple) asterisk denotes significance at 10% (5%, 1%) level

FIGURE 1. Gasoline Case: Likelihood ratio inverse. 80% critical value

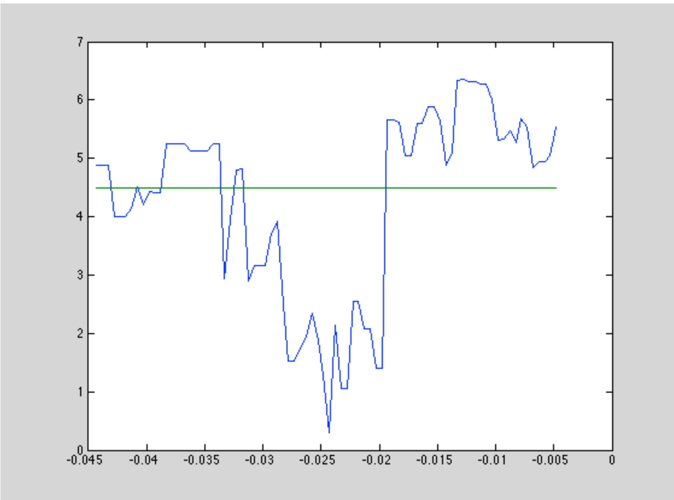
Germany



U. Kingdom



France



Italy

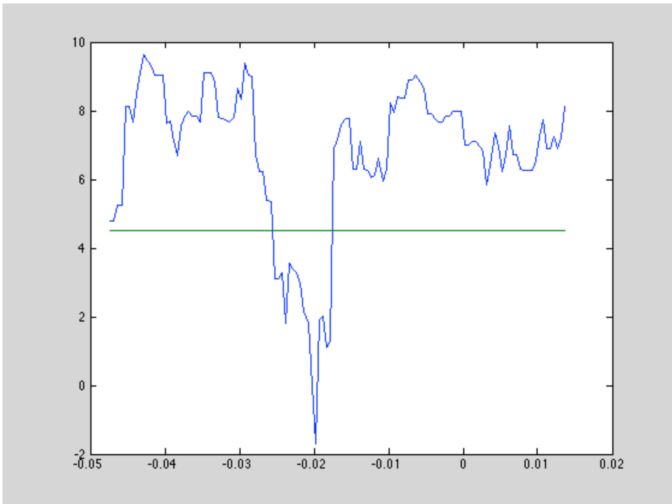
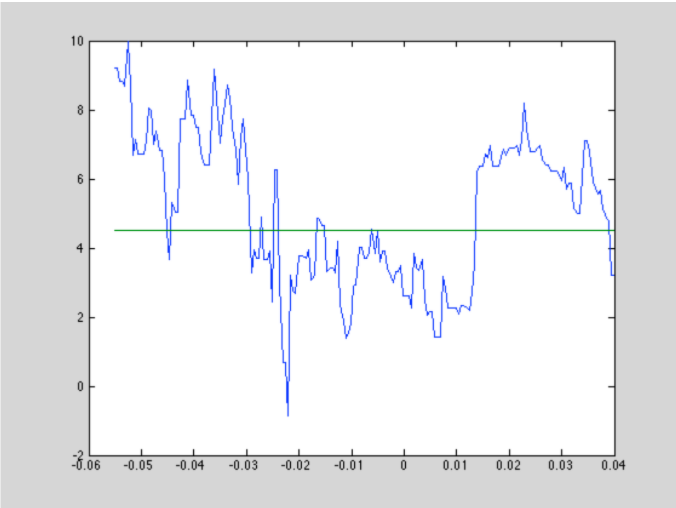
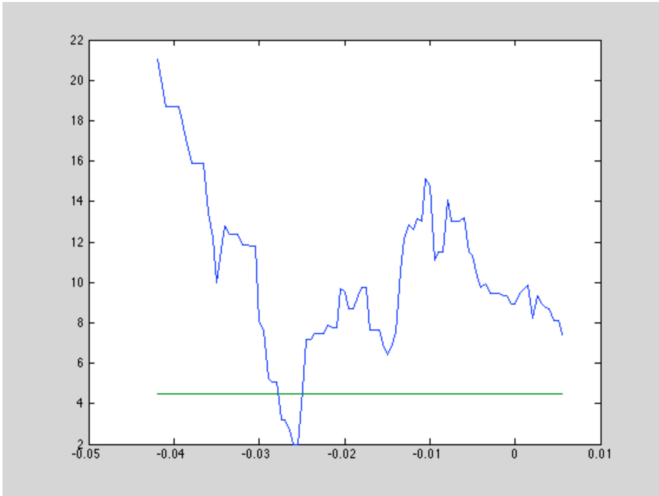


FIGURE 2. Diesel fuel Case: Likelihood ratio inverse. 80% critical value

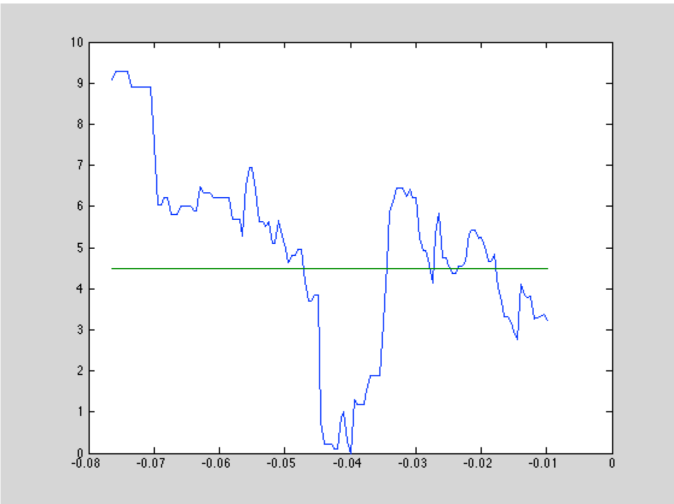
Germany



U. Kingdom



France



Italy

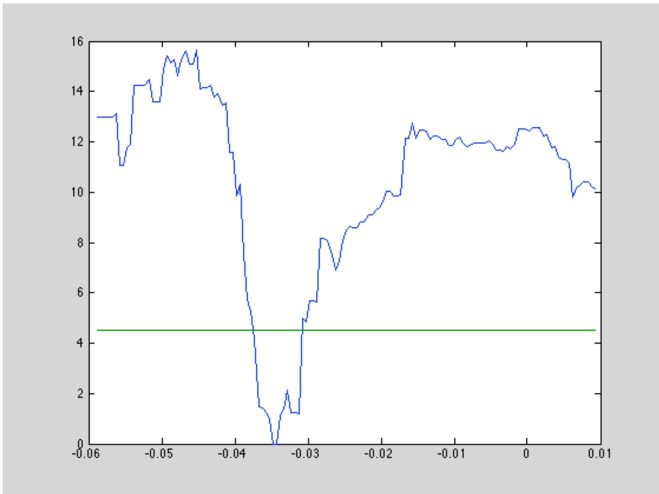


FIGURE 3: Response of Gasoline retail Price to an increase in Crude-Oil Price in Germany (Markov-switching)

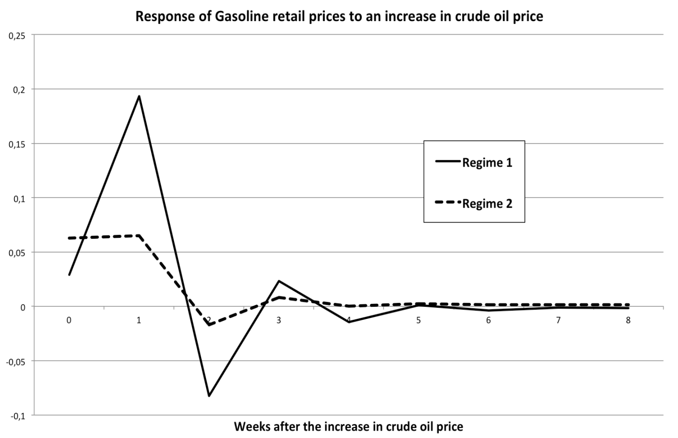


Fig. 3.a

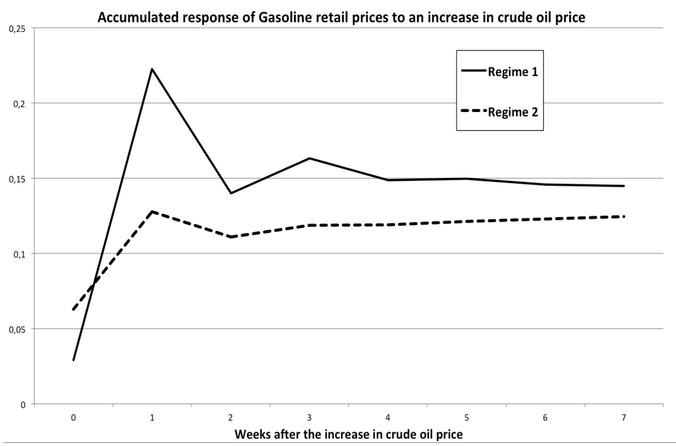


Fig. 3.b

FIGURE 4: Response of Diesel retail Price to an increase in Crude-Oil Price in Germany (Markov-switching)

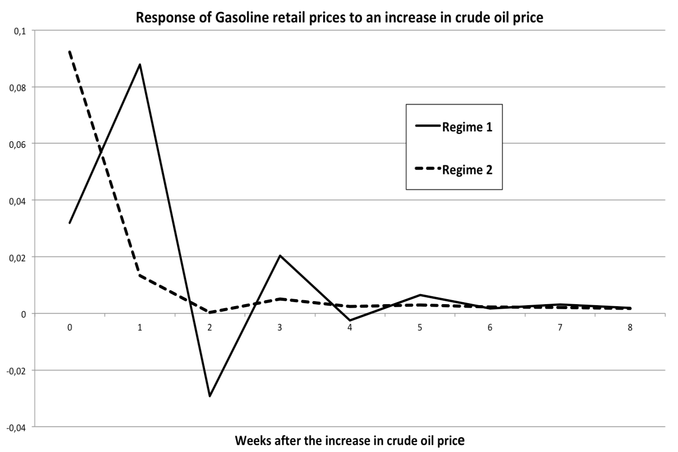


Fig. 4.a

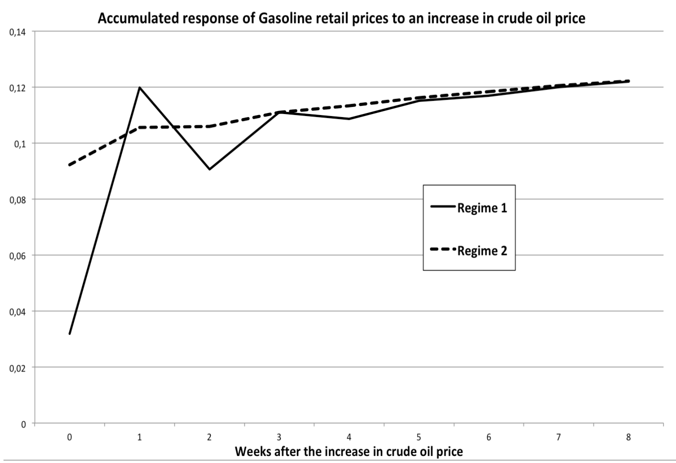


Fig. 4.b

Table 7: Test for rockets and feathers hypothesis

			Test				Test
	Gasoline		$H_0: \{\alpha_1 = \alpha_2 = 0\}$ $H_1: \{\alpha_1 > 0, \alpha_2 < 0\}$		Diesel		$H_0: \{\alpha_1 = \alpha_2 = 0\}$ $H_1: \{\alpha_1 > 0, \alpha_2 < 0\}$
	α_1	α_2	pvalue Statistic		α_1	α_2	pvalue Statistic
Germany	4.35 (0.31)	-4.54 (0.35)	0.00		3.12 (0.85)	-4.04 (0.93)	0.00
R^2	0.5897				0.7848		
U. Kingdom	11.97 (0.76)	-9.29 (0.62)	0.00		4.25 (0.82)	-8.69 (0.67)	0.00
R^2	0.9094				0.3658		
France	9.46 (0.55)	-9.55 (0.61)	0.00		5.16 (0,80)	-4.05 (0.86)	0.00
R^2	0.6677				0.8490		
Italy	12.78 (0.96)	-12.04 (1.00)	0.00		9.44 (1.20)	-8.40 (1.18)	0.00
R^2	0.8758				0.8925		

p-value (values under {0.01,0.05,0.1}, lead to a rejection of the null hypothesis {99%,95%,90%})

Table 8: Asymmetries Summary

		GERMANY		U. KINGDOGM		FRANCE		ITALY	
		Short-run	**Long-run**	**Short-run**	**Long-run**	**Short-run**	**Long-run**	**Short-run**	**Long-run**
Gasoline	**TAR-ECM**	*No* asymmetries	*No* asymmetries	*No* asymmetries	*No* asymmetries	*No* asymmetries	*No* asymmetries	*No* asymmetries	*No* asymmetries
	Switching Markow	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior
Diesel	**TAR-ECM**	Asymmetries *Not in line* with rockets and feathers behavior	*No* asymmetries	*No* asymmetries	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *Not in line* with rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *Not in line* with rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior
	Switching Markow	Asymmetries *Not line with* rockets and feathers behavior	*No* asymmetries	*No* asymmetries	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *Not in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior	Asymmetries *in line with* rockets and feathers behavior