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Smooth Transition Models in Price Transmission

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Abstract

Consumers complain that retail prices of petroleum products increase instantly whenever prices of crude oil increase but take a long time to fall after crude oil price decreases. This apparent discrepancy attracts significant attention in the applied literature, as it might imply a welfare transfer from individual consumers to big oil companies. Unfortunately, the way the "rocket and feathers" phenomena are modelled suffers from unrealistic assumptions. In this article we analyse the price transmission between energy products at different processing tiers in the European Union using innovative smooth transition models. We find previously missed patterns, consistent with transactional costs theories and casting some doubts on the negative welfare effect of asymmetric price transmission. *JEL Classification: Q410, C220, D400.*
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1 Introduction

Modelling petroleum prices continues to receive significant attention in the applied literature. In particular, researchers focus on price transmission, i.e. the way developments in at international markets are transmitted downstream to prices paid by the end users. This interest in price transmission is largely driven by its perceived asymmetric (non-linear) nature, i.e. the fact that energy prices seem to respond quickly to increases in costs but delay falling when the market situation is more favourable.

Recently, the issue of price transmission has increased in importance as both market participants and researchers witness violent developments in international markets for oil, the prices of which reflect continuing unrest in the Middle East and China's growth. Under those circumstances, any asymmetry in price transmission could result in a welfare transfer with sellers temporarily enjoying higher revenues and lower costs and buyers not benefiting from lower prices as quickly as they should. Figure 1 summarizes the resulting situation and depicts the per-unit welfare transfer.

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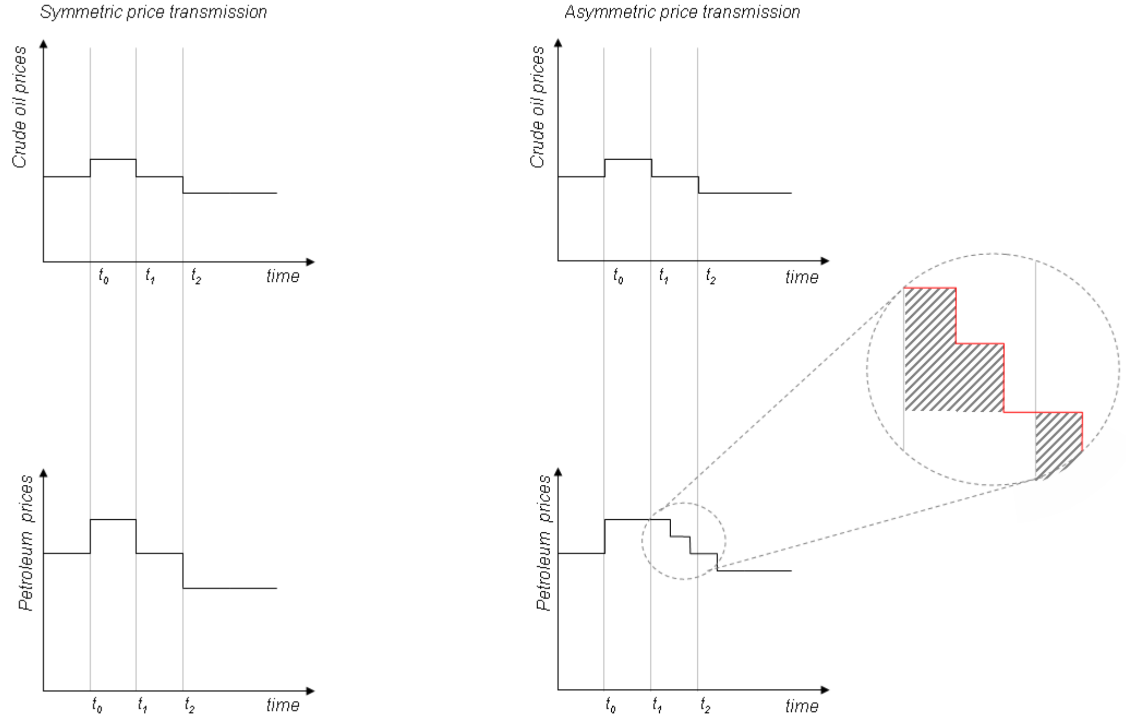
Figure 1: Example of asymmetries in price transmission.[1]



Usually, such a situation (referred to as Asymmetric Price Transmission - here APT) is seen as a sign of market failure - see Borenstein, Cameron & Gilbert (1997) - and a reason for government agencies to start antitrust investigations - examples include Federal Trade Commission (2006), General Accounting Office (1993) for the USA, Monopolies and Mergers Comission (1990) and Office of Fair Trading (1998) for the UK and Competition Bureau (1997) for Canada. Applied researchers follow government agencies, also focusing on transmission occurring in one country-wide market for one product priced between two tiers (pricing stages). The tools and data used in those studies, however, constrain the research in terms of economic behaviour covered (as only a part of the transmission chain is being analysed) and the way this behaviour is modelled (as the estimation techniques impose certain restrictions on the nature of non-linearities).

In this article, we attempt to re-visit the issues of price transmission in a multi-product, -country and -tier setting with the help of smooth transition models. Previous studies focus on single country / product environment and assume instantaneous shift between two pricing regimes - one for the times of increased margins for sellers - which assumed slow return to equilibrium and extra profits for the sellers, and one for the times of squeezed margins - which assumed quick return to equilibrium. Our framework allows us to relax those assumption and analyse price transmission as

[1]Two top panels depict oil price changes, while two bottom panels depict the downstream responses in the symmetric and asymmetric versions - right and left panels, accordingly. The inset shows the details of the response. The shaded area represents per-unit welfare transfer from downstream to upstream agents.

a smooth transition between two or three pricing regimes, without imposing harsh restrictions on the manner in which agents behave. While our results regarding the presence of non-linearities obtained following this approach largely confirm earlier studies, the estimation results indicate that in a large proportion of cases, the non-linearities do not necessarily imply a welfare transfer but instead could indicate market frictions and transactional costs, associated with an exponential transition function. The resulting pattern indicates that small changes in crude oil prices that do not significantly affect the margins are often left uncorrected. This, combined with cross-country and -product differences in price transmission, indicate that overall impact of global developments in crude oil prices affects retail petroleum product prices (and indirectly the overall price level) in not uniform and has to be tackled on a case-by-case basis.

We start by summarizing the state of the research into APT in Section 2. We focus on the shortcomings of the current APT methodology which we want to rectify using the smooth transition models. In Section 3 we apply the proposed tools to a pan European, multi-product dataset which covers all tiers in the pricing chain. We discuss the results and present suggestions for further research in Section 4.

1.1 Contribution

In this article we analyse the price transmission in 25 EU countries utilizing a multi-tier, multi-product dataset with the help of STAR models. We aim to:

- expand the traditional linear cointegration analysis with the help of the non-linear cointegrating tools developed by Kapetanios, Shin & Snell (2006);
- test for the presence of non-linearities in price transmission using the smooth transition approach proposed by Teräsvirta (1994);
- establish the nature of non-linearities using the framework by Escribano & Jordá (2001);

The first point constitutes an improvement over previous studies in the sense that it allows us to widen the sample by inclusion of additional cases of price transmissions. This is possible as the traditional cointegration tools often mis-identify signs of APT as spurious regression (see Monte Carlo comparisons in Kapetanios et al. (2006, Tables 1-3)), so that reliance on purely linear tools would result in exclusion of such an asymmetric transmission from the study. By utilizing non-linear cointegration tools we ascertain that such cases would not be incorrectly labelled as spurious regressions.

The second goal boils down to identification of transmissions where the equilibrium-reverting process is non-linear and can potentially be a welfare-decreasing APT. Previously used models were either notoriously difficult to use for testing purposes (SETAR) or suffered from low power or arbitrary assumptions (ECM models). STAR models do not suffer from those disadvantages as they:

- are more flexible, allowing the non-linearities to take logistic or exponential shape;

- encompass SETAR models as an extreme case (with logistic transmission function and smoothing parameter set to ∞);
- assume smooth transition between the regimes which is a more realistic assumption than the complete and instantaneous regime change characteristic of SETAR models.

The third point involves utilizing the testing strategies proposed by Teräsvirta (1994) and Escribano & Jordá (2001) to identify the nature of asymmetries.

2 Traditional APT modelling

All price transmission studies utilize a time series framework to test for the null of symmetric price transmission (hereafter SPT) against the alternative of APT. Meyer & Cramon-Taubadel (2004) and Frey & Manera (2007) present comprehensive literature reviews which indicate that the most common tools used are modifications of the standard Error Correction Model (ECM) by Engle & Granger (1987) and regime-switching models of the Self Exciting Threshold Autoregressive (SETAR) class by Tong (1978) and Tong (1990).

2.1 ECM Modelling

Assuming that upstream and downstream prices (denoted x and y respectively) are related to each other, there must exist an Error Correction Mechanism that governs the revision of series to their long-run equilibrium relationship - Engle & Granger (1987).

$$\Delta y_t = \sum_{l=1}^{n} \alpha_l \Delta y_{t-l} + \sum_{j=0}^{m} \beta_j \Delta x_{t-j} + \gamma ECT_{t-1} + \nu_t \tag{1}$$

This model expresses the short-run adjustment of the downstream prices as a sum of short-run variations of upstream prices (governed by the β coefficients), portions of its own past changes (governed by the α coefficients) and a part (γ) of the last period's disequilibrium proxied by the error correction term (ECT). The ECT can be estimated simultaneously (within the model) as proposed by Stock & Watson (1993), i.e. $ECT_{t-1} = y_{t-1} - \delta_0 - \delta_1 x_{t-1}$ or modelled separately in level estimation of y on x, as advocated by Engle & Granger (1987) - $ECT_{t-1} = \hat{e}_{t-1}$.

Both formulations can be adopted for the purposes of an APT analysis by splitting the short-run and / or long-run variables according to the sign of price changes - as proposed by Wolffram (1971), Houck (1977), Engle & Granger (1987) and Granger & Lee (1989). Defining ECT in this way and denoting $x^+ = max(0, x)$, this results in (1) becoming:

$$\begin{aligned} \Delta y_t = \; & \textstyle\sum_{j=0}^{m^+} \beta_j^+ (\Delta x_{t-j})^+ + \sum_{i=0}^{m^-} \beta_i^- (\Delta x_{t-i})^- \\ & + \gamma^+ e_{t-1}^+ + \gamma^- e_{t-1}^- + \nu_t \end{aligned} \tag{2}$$

One should remember that although only two regimes for each variable exist, the overall number of regimes, i.e. combinations of coefficients, is a function of the lag structure chosen. For example, the maximum number of regimes in (2) equals $2^{max(m^+,m^-)+max(n^+,n^-)+1}$. This prohibits tracking down the extent of APT over time and identifying the impact of economic developments on APT.[2]

Testing for the asymmetry using (2) can be based on (i) individual tests of equality of same-period parameters (e.g. $H_0 : \beta_i^+ = \beta_i^-$) for a given i, or on (ii) joint tests of the null of equality of all SR coefficients (e.g. $H_0 : \beta_i^+ = \beta_i^-$) either for $\forall_{i=1,\ldots,max(m^+,m^-)}$ as proposed by Bettendorf, der Geest & Varkevisser (2003) or for $\forall_{i=1,\ldots,min(m^+,m^-)}$ as proposed by Ye, Zyren, Shore & Burdette (2005). However, all techniques are imperfect, as several studies have shown that they have low power (Cook (1999) and Cook, Holly & Turner (1999)) and require bootstrapping in small samples (Galeotti, Lanza & Manera (2003)).

The main reservation towards ECM models (voiced first by Chen, Finney & Lai (2005)) is concerned with the way those models misinterpret market behaviour. As an example, consider two alternative situations: in the first one, at t upstream cost increases by 5 units and then decreases by 0.1 units at $t+1$. In the second one, it increases by 4 units at t and then increase once more by 0.9 units at $t+1$. The end result is exactly the same in both cases, but (2) differentiates between them.

2.2 SETAR Models

The easiest way of avoiding problems with unidentifiable regimes and inconsistent classification of market developments is to create a system in which *all* variables belong to the same, easily identifiable regime. Such systems stem from simple autoregressive models. As an example, consider a simple AR(p) model by Box & Jenkins (1970) for a time series e_t:

$$e_t = \gamma_0 + \gamma_1 e_{t-1} + \gamma_2 e_{t-2} + \ldots + \gamma_p e_{t-p} + \nu_t \tag{3}$$

where γ_i for $i = (1, 2, \ldots, p)$ are AR coefficients constant over time; $\nu_t \overset{iid}{\sim} WN(0, \sigma^2)$ stands for white-noise error term with constant variance. When written in a vector form it becomes:

$$e_t = \mathbf{X_t}\gamma + \sigma\nu_t \tag{4}$$

where $X_t = (1, e_{t-1}, e_{t-2}, \ldots, e_{t-p})$ is a column vector of variables; γ is the vector of parameters $\gamma_0, \gamma_1, \gamma_2, \ldots, \gamma_p$. When $e_{t-1} = y_{t-1} - \delta_0 - \delta_1 x_{t-1}$, such a model is a simplification of (1) as it utilizes the Dickey-Fuller framework to show how the pricing system reverts to the equilibrium following a change in upstream costs.

In order for (3) to model APT it is enough to allow for two sets of distinct parameters controlling adjustment to the equilibrium and assume that APT occurs because the pricing system switches from one regime to the other.[3] This regime switch is assumed to be triggered by a weakly exogenous variable w_t surpassing a given threshold - hence the name of the augmented class of models is *Threshold* AR

[2] A possible solution to this problem would involve recursive / rolling estimation of β^+ and γ^+. This approach is used in Reilly & Witt (1998) and Wlazlowski (2003).

[3] While in principle, SETAR models could consist of more than two regimes, the applied literature utilizes only SETAR(2) models. Therefore, throughout this article we refer to SETAR(2) model simply as SETAR.

models TAR. In such a setting, equation (3) becomes:

$$e_t = \mathbf{X_t}\gamma^{(j)} + \sigma^{(j)}\nu_t \text{ if } r_{j-1} < w_t < r_j \tag{5}$$

where: $\gamma^{(j)}$ is the vector of parameters $\gamma_0^{(j)}, \gamma_1^{(j)}, \gamma_2^{(j)}, \ldots, \gamma_{p^{(j)}}^{(j)}$ governing the process in j^{th} regime (assuming that the AR process is of the order $p^{(j)}$ in that regime) and $-\infty = r_0 < r_1 < \ldots < r_k = +\infty$ are $k-1$ non-trivial thresholds dividing the domain of w_t into k different regimes, $j = 1, 2, \ldots, k$.

When $w_t = y_{t-d}$, with d (called delay parameter) set to be a positive integer, the dynamics of y_t are determined by its own past values. After such a self-governing mechanisms those models are dubbed *Self-Exciting* TAR or *SE*TAR.

While application of SETAR models to APT modelling is straightforward, testing the null of symmetric transmission against alternative hypothesis of non-linear adjustment towards the equilibrium is more complicated as the non-linear threshold parameters (rs) are not defined under the null. This results in a nuisance parameter problem and prohibits application of the traditional OLS testing framework - see Davies (1987) for a discussion. Two distinct ways used to overcome this problem are (i) arranged autoregression proposed by Tsay (1989) and (ii) sup-LR test combined with simulations and bootstrap proposed by Hansen (1997) and Hansen (1999). However, the former leaves some crucial elements up to the discretion of a researcher while the latter requires computationally cumbersome simulations and bootstrap.

An additional disadvantage of SETAR models is that they assume that market behaviour changes drastically as the threshold variable exceeds the predetermined level. Such an abrupt change might be applicable in some situations - for example when analysing pricing of non-storable products such as electricity - Misiorek, Trueck, Weron, Misiorek, Trueck & Weron (2006) or technical phenomena such as electricity congestion - Haldrup & Nielsen (2006), but is less likely to occur in petroleum markets.

2.3 Non-linear Models of Price Transmission - Literature Review

In this section we summarize applied research into the non-linearities in petroleum product price transmission. We are interested in studies that focus purely on testing for APT in a manner consistent with the concept of cointegration. Therefore, we omit some pre-1990 studies and micro-economic analyses. Table 1 presents the summary of applied research described below.

Sumner (1990) is the first to analyse the transmission of monthly prices and labour costs for the UK market using the standard ECM model. After the null of equal adjustment to short-run changes is rejected, he concludes that UK transmission of leaded petrol prices is asymmetric. Bacon (1991) confirms his findings, but using bi-weekly data and different assumptions about the nature of the long-run equilibrium relationship between crude oil and retail petrol prices. Manning (1991) revisits UK market using longer sample and model enriched by additional dummies for price changes again to find traces of APT. Kirchgassner & Kubler (1992) apply bi-directorial version of ECM to German market by splitting the sample into two sub-samples - before and after sudden increase in market liquidity. The authors find signs of APT in the former but not the latter and concludes that APT is linked to market liquidity.

For the USA, Norman & Shin (1991) apply methodology similar to that of Bacon (1991) but fail to reject the null of symmetric transmission. Borenstein & Shephard (1996) revisit the US market and find that the city-level transmission is asymmetric, even when accounting for demand and supply effects. Borenstein et al. (1997) attempt to estimate the extent of APT using simulations from the ECM model and conclude that APT is present on the US market at the majority of pricing tiers. Balke, Brown & Yucel (1998) apply an analogous framework to higher frequency data, but obtain mixed results, with APT found only at some transmission tiers. Eltony (1998) analyses both UK and US markets and finds signs of APT in both of the markets.

Reilly & Witt (1998) re-visit the UK market using ECM model and find the signs of APT coming both from upstream prices and from the GBP-USD exchange rate movements. Energy Information Agency (1999) utilize similar tools to find APT in a number of local US markets while Asplund, Eriksson & Friberg (2000) find APT in firm-level data for one chain of filling stations in Sweden. Berardi, Franzosi & Vignocchi (2000) analyse the Mediterranean markets for leaded and unleaded petrol and discover that APT is present in transmission of unleaded but not leaded petrol.

Godby, Lintner, Stengos & Wandschneider (2000) utilize a threshold regime switching model for Canada (with lagged crude oil changes as threshold variable) and find signs of APT. Indejehagopian & Simon (2000) analyse German and French heating oil markets and find the latter to be asymmetric. Galeotti et al. (2003) use bootstrapped ECM to analyse transmission in five EU countries (Germany, France, Italy, Spain and the UK) at four different pricing tiers. The results are mixed with 10 out of 15 cases indicating APT. Johnson (2002) applies a framework similar to that of Borenstein et al. (1997) but using city-level data and finds wide-spread APT. Bachmeier & Griffin (2003) re-visit models by Borenstein et al. (1997) but with different representation of ECT, obtaining different results. Driffield, Ioannidis & Peel (2003) find APT in UK the transmission of petrol prices using VAR version of traditional ECM and some far-reaching assumptions (Saudi crude oil determining UK prices, full pass-through of costs downstream and impact of CPI on producer prices). This is confirmed by Wlazlowski (2003) who utilizes both TAR and ECM models to find APT in the UK. Lewis (2004) also finds APT using a combination of these two models, but he uses station-level US data. Chen et al. (2005) follow the same route only to confirm that APT is present at some, but not all transmission tiers. Contin, Correlj & Palacios (2004) follow Kirchgassner & Kubler (1992) and analyse the transmission from crude oil to unleaded petrol in Spain using the ECM framework and sample split. The results mirror those obtained for Germany by Kirchgassner & Kubler (1992). Radchenko (2005*a*) obtains similar results for the US markets with the help of VAR version of ECM models and finds that the degree of asymmetry in prices declines with an increase in oil price volatility.

Radchenko (2005*a*) and Wlazlowski, Binner, Giulietti, Joseph & Nilsson (2006) both utilize stochastic switching models analogous to those by Hamilton (1989) to find evidence of APT in the national and New York markets (respectively). Grasso & Manera (2007) revisit the five-country sample of Galeotti et al. (2003) using a combination of ECM and SETAR models, again to obtain mixed results, confirming that APT is present, mainly at the distribution stage. Kaufmann & Laskowski (2005) analyse the heating oil and petroleum transmission using the ECM framework and find APT to depend on refiners' utilization rates and local state-wide economic situation. Rao & Rao (2005) revisit the work of Borenstein et al. (1997) with different ECT formulation and data of different frequency and conclude that both elements affect the results of APT inference. Ye et al. (2005) analyse the petrol price transmission at several levels of geographical aggregation and conclude that pricing is responsive to spatial aggregation. Denni & Frewer (2006) attempt to analyse transmission of unleaded petrol, gasoil, kerosene, fuel oil and naphtha using ECM model enriched by the GARCH mechanism and proxies for refiners' margins. The canonical models do not lend any support to the presence of APT, but when refiners' margins are accounted for, the null of SPT is rejected with all force in all cases. Hosken, McMillan & Taylor (2007) decide to use superior quality data on pricing at the filling station level around the Washington DC area. The results of ECM model estimation indicate that pricing differs between stations, and most of the inter-station variance can be explained by brand affiliation, local competition or other station-specific attributes.

The picture of APT emerging from the applied literature is segmented as it covers many (but not all) products and markets across many years. Multi-national and multi-product studies are rare, just as studies that do not impose rigorous shape of non-linearities. While the most common tools used include univariate ECMs and SETARs, their drawbacks discussed above are not addressed.

Table 1: Testing for APT - Overview

Author	Model	Product[1]	Tiers[2]	Country	Frequency[3]	Coverage	Results[4]
Sumner (1990)	ECM	ULP	C→R	UK	M	III'82-XXI'89	Y
Bacon (1991)	ECM	LP	C→R	UK	2W	VI'82-I'90	Y
Manning (1991)	ECM	LP	C/T→R	UK	M	I'73-XII'88	Y
Norman & Shin (1991)	ECM	LP	C→W→R	US	M	I'82-XII'90	N
Kirchgassner & Kubler (1992)	Other	HO/LP	S→R	DE	M	I'72-XII'89	M
Borenstein & Shephard (1996)	ECM	ULP	C→ R	US	M	I'82-XII'91	Y
Borenstein et al. (1997)	ECM	ULP	C→S→W→R	US	2W	III'86-XII'92	M
Balke et al. (1998)	ECM	ULP	C→S→R	CA	W	I'87-IIX'96	Y
Eltony (1998)	ECM	LP	C→R	MN	M	I'80-VI'96	Y
Reilly & Witt (1998)	ECM	LP	C→R	UK	M	I'82-VI'95	Y
Energy Information Agency (1999)	ECM	ULP	C→S →R	US	W	X'89-IV'93	Y
Asplund et al. (2000)	ECM	LP	C/T→R	SE	D	I'80-XII'96	Y
Berardi et al. (2000)	ECM	LP/ULP	C/T→R	IT	W	X'91-II'00	M
Godby et al. (2000)	SETAR	ULP	C→R	CA	W	I'90-XII96	Y
Indejehagopian & Simon (2000)	ECM	HO	W→R	MN	M	I'87-XII'97	M
Galeotti et al. (2003)	ECM	LP/ULP	C→S →R	MN	M	I'85-VI'00	Y
Johnson (2002)	ECM	ULP,DO	W→R	US	W	VII'96-VI'98	Y
Bachmeier & Griffin (2003)	ECM	ULP	C→S→W→R	US	DW	II'85-XI'98	M
Bettendorf et al. (2003)	ECM	ULP	W/T→R	NL	D	I'96-XII'01	M

Continued on next page

Table 1 – continued from previous page

I	II	III	IV	V	VI	VII	VIII
Driffield et al. (2003)	VAR	LP/ULP	C→R	UK	M	I'73-IV'00	Y
Wlazlowski (2003)	Both	LP	C→R	UK	M	I'78-XII'02	Y
Contin et al. (2004)	ECM	ULP	C→R	SP	W	I'93-XII'02	Y
Lewis (2004)	Both	ULP	W→R	US	W	I'00-XII'01	Y
Chen et al. (2005)	SETAR	ULP	C→S→R	US	W	I'91-III'03	
Radchenko (2005*a*)	ECM	ULP	C→S→R	US	M	III'91-II'03	Y
Grasso & Manera (2007)	Both	(U)LP	C→S→R	MN	M	I'85-III'03	M
Kaufmann & Laskowski (2005)	ECM	ULP/HO	C→W→R	US	M	I'86-XII'02	M
Radchenko (2005*a*)	ECM	ULP	C→S→R	US	M	III'91-II'03	Y
Radchenko (2005*b*)	Both	ULP	C→R	US	M	III'91-II'03	Y
Rao & Rao (2005)	ECM	LP	C→R	US	M	I'78-XII'04	N
Ye et al. (2005)	ECM	ULP	W→R	US	W	I'00-XI'03	Y
Denni & Frewer (2006)	ECM	MN	C→R	NL	M	I'90-IX'05	Y
Wlazlowski et al. (2006)	SETAR	ULP	W→R	US	D	VI'00-XI'05	Y
Hosken et al. (2007)	ECM	ULP	W→R	US	W	I'97-XII'99	M
Lewis (2007)	Various	ULP	W→R	US	D	VI'00-XI'05	Y

[1] Product: LP - leaded petrol, ULP - unleaded petrol, HO - heating oil, D - diesel oil, MN - various products;
[2] Tiers: C - market level on which crude is traded, R - retail, W - wholesale, EX - the exchange rate;
[3] Frequency: W - weekly data, 2W - bi-weekly, M - monthly;
[4] Results: Y - the null of SPT rejected, N - the null of SPT not rejected, M - mixed results.

2.4 STAR Models

Just like the SETAR models, Smooth Transition AR (STAR) models can be thought of in terms of extension of standard AR models, incorporating changes in the model parameters. In contrast to SETAR models, however, STAR models assume that such a change is gradual (hence the name). A simple model of this family can be depicted as following modification of (4):

$$\hat{e}_t = \mathbf{X_t}\gamma^{(0)}(1 - G(w_t, \zeta, c)) + \mathbf{X_t}\gamma^{(1)}G(w_t, \zeta, c) + \sigma^{(j)}\nu_t \tag{6}$$

or equivalently:

$$\hat{e}_t = \mathbf{X_t}\gamma^{(0)} + \mathbf{X_t}(\gamma^{(1)} - \gamma^{(0)})G(w_t, \zeta, c) + \sigma^{(j)}\nu_t \tag{7}$$

where $G(w_t, \zeta, c)$ is the continuous transition function, bounded between 0 and 1 and w_t is the transition variable, usually defined in the self-exciting way as e_{t-d}.

Given the above specification, STAR models could be interpreted as composed of a continuum of regimes, each associated with different value of transmission function. The way these regimes reflect non-linearities is determined by the transition function used. Most commonly applied functions include first-order logistic function - $G(w_t, \zeta, c) = \frac{1}{1+e^{-\zeta(w_t-c)}}$ which result in logistic STAR (LSTAR) model, or a second-order exponential function - $G(w_t, \zeta, c) = 1 - e^{-\zeta(w_t-c)^2}$ which result in exponential STAR (ESTAR) model;

LSTAR models resemble SETAR models in the sense that they also assume the presence of two regimes between which the transmission occurs as w_t changes. The difference lies in the fact that SETAR models assume a sudden regime shift, while LSTAR models allow for gradual transition between the regimes, which can differ according to the value of ζ coefficient. Conversely, ESTAR models assume different ordering of regimes with one regime operating for extreme positive and negative values of w_t and the internal regime centered around the averaging parameter - c.

Figure 2 presents comparison between regime transition assume in ESTAR, LSTAR and SETAR models. Figure 3 describes how those differences translate into speed of adjustment of prices towards the long-run equilibrium.[4]

Figure 2: Comparison of Non-linear Models

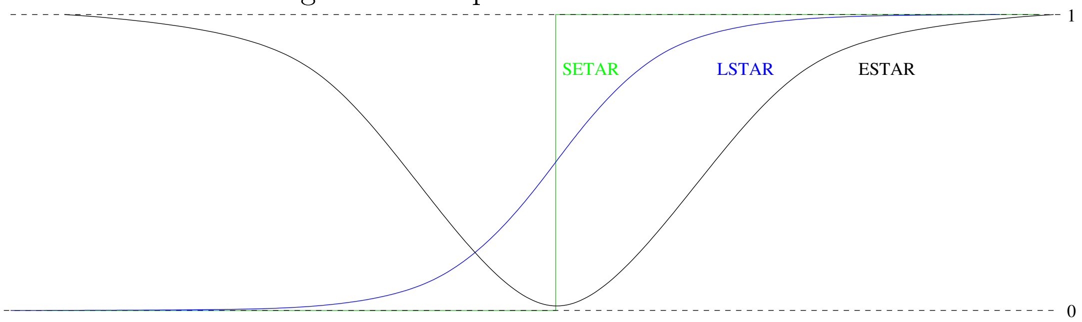
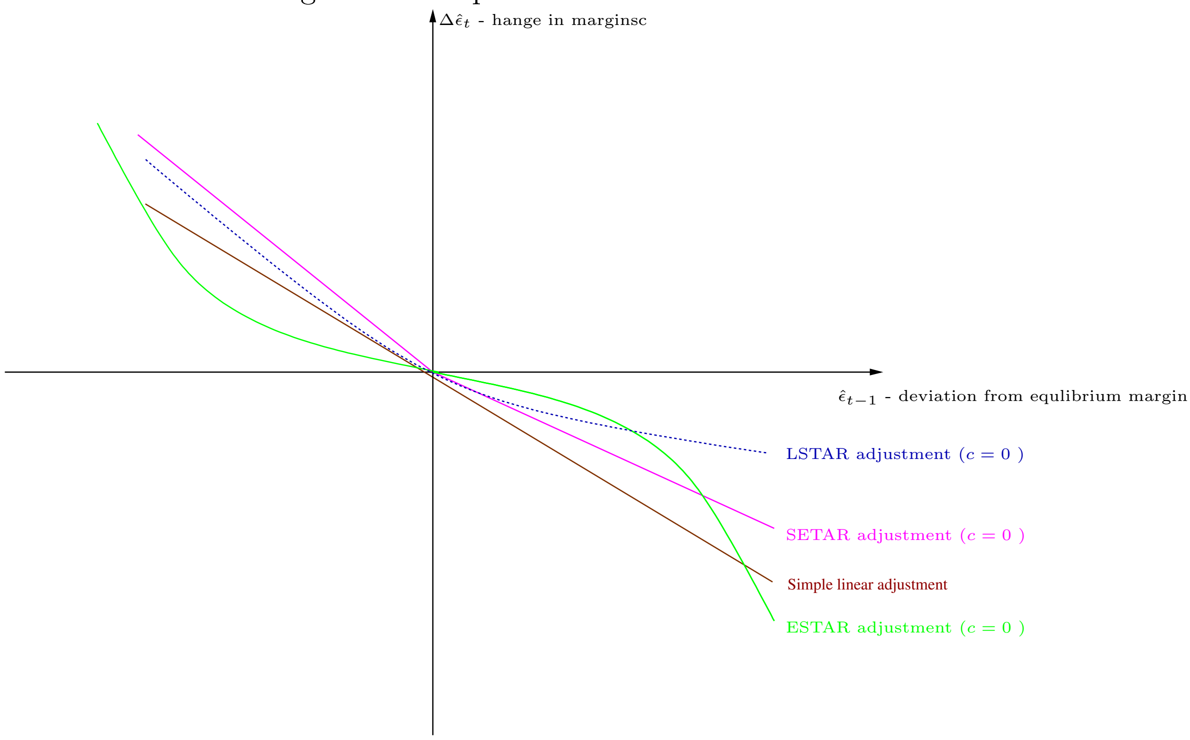


Figure 3: Comparison of Non-linear Models



In economic terms the situation depicted in Figures 2 and 3 corresponds to:

- for SETAR models - faster elimination of negative disequilibrium (equivalent to squeezed margins for the transmission agents) compared to the positive disequilibria (which imply swollen margins);
- for LSTAR models - a situation similar to that with the SETAR model but with the attractor strength depending on the magnitude and size of the dise-

[4]As an illustration, we also present instantaneous adjustment (straight 45-degree line) and symmetric price transmission (straight line).

quilibrium - large negative disequilibria are eliminated much faster than small negative disequilibria;

- for ESTAR models - a situation when large disequilibria (both positive and negative) are eliminated faster than the smaller ones.

Depending on the autoregressive parameters within the regimes, all types of non-linearities can give rise to a welfare decreasing APT depicted in Figure 1, but only the extreme case (i.e. SETAR models with built-in instantaneous switch between two regimes) has been analysed so far in practice. LSTAR models were not used although the smooth transmission between the regimes they assume is more likely to happen than the instant and complete change assumed by SETAR models. Similarly, ESTAR models were largely disregarded although the economic phenomena giving rise to them (transactional costs and market frictions) are much more likely to occur than collusion and market imperfections commonly considered responsible for SETAR-type asymmetries.

2.5 Application of STAR Models

The STAR model rewritten as (7) can be tested against the linear alternative using Taylor expansion of the transition function $G(\hat{e}_{t-d}, \zeta, c)$ around $\zeta = 0$:

Since every nth order expansion of either of the transition function is nested in a following auxiliary regression:

$$\hat{e}_t = \zeta_0 + \zeta_1' * \mathbf{X_t} + \zeta_2' * (\mathbf{X_t} * \hat{e}_{t-d}) + \textstyle\sum_{i=3} \zeta_i' * (\mathbf{X_t} * \hat{e}_{t-d}^{i-1}) \tag{8}$$

where e_t is the error term and $\hat{e}_{t-d}$ is the argument for the transmission function.

Given the above, it is possible to test for the presence and type of non-linearities, simply by estimating the appropriate auxiliary regression and determining which expansion suits the model better. A simple test for the presence of nonlinearity (as proposed by Teräsvirta (1994)) would involve estimation of third order expansion (n=3) and then testing for the null of linearity $H_0 : \zeta_2 = \zeta_3 = \zeta_4 = 0$. If the null is not rejected, simple AR(p) model govern price adjustment and APT is not present. Whenever the delay parameter d is unknown, Teräsvirta (1994) advocates performing the estimation of the expansion function over all possible values of d and choosing the value for which the null is rejected with the smallest p-value.

Escribano & Jordá (2001) suggest using a 4^{th} order Taylor expansion and introduce a testing procedure that offers a way of distinguishing between the two transition functions. The end result involves estimation of 8 for n=4 and the following testing strategy:

1. test $H_0 : \zeta_5 = \zeta_4 = \zeta_3 = \zeta_2 = 0$ - if rejected proceed, if not use AR;

2. test $H_{0L} : \zeta_5 = \zeta_3 = 0$ with the help of an F-test denoted F_L;

3. test $H_{0E} : \zeta_4 = \zeta_2 = 0$ with the help of an F-test denoted F_E;

4. if the minimum p-value corresponds to F_E select LSTAR, otherwise select ESTAR.

3 Empirical Analysis

3.1 Data

The data used for our empirical analysis comprises three sets of weekly series of:

- USD prices of Brent crude oil which was found to be the price-leading crude oil for the petroleum markets in the EU - Reilly & Witt (1998);
- net-of-taxes retail prices for:
  - EURO-95 unleaded petrol - EURO;
  - Diesel fuel - DIESEL;
  - heating oil - HGASOIL;
  - Lead replacement petrol - SUPER;
  - Liquefied Petroleum Gas - LPG;
  - two kinds of fuel oils (low and high sulphur) - RFO1/2,

  charged in 25 EU countries (see below);
- USD spot prices of seven above-listed products quoted in the hub of EU petroleum trade - Santos Manzano (2005) - Amsterdam-Rotterdam-Antwerp (ARA) triangle;
- exchange rates between local currencies and USD, necessary as crude oil prices are quoted in USD.

The ARA prices were obtained from Platt's (a market consultancy). Retail prices come from the OilBulletin published by the European Commission. The length of period covered differs on a country and product basis. The longest sample for the EU-15 countries[5] stretches back to January 1994, while the data for the EU-10 countries[6] starts in mid-2004. All series end in December 2005. Data on the exchange rates between local EU currencies and USD at relevant times comes from DataStream. The data follow the official exchange up until the introduction of Euro (January 2002), after which the exchange rate follows the EUR/USD exchange rate. The prices expressed in Euro were converted to the original currencies using fixed parities established by the European Central Bank. We denote the retail prices as downstream prices (here DSP), ARA prices as midstream prices (here MSP) and crude oil prices as upstream prices (here USP). Using that notation, the analysis covers the price transmission between the following tiers:

- from crude oil to retail products (USP-to-DSP indirect transmission);
- from crude oil to ARA spot prices (USP-to-MSP direct transmission);
- from ARA spot prices to retail prices (MSP-to-DSP direct transmission).

[5]Austria, Belgium, Denmark, Germany, Finland, France, Great Britain, Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, and Sweden.

[6]Cyprus, the Czech Republic, Estonia, Hungary, Lithuania, Latvia, Malta, Poland, Slovenia, Slovakia.

3.2 Cointegration

As the first step in the analysis, we estimate the following equation for each upstream-downstream product pair for every country, product and tier:[7]

$$ln(y_t) = \alpha + \beta ln(x) + \gamma ln(ex^k) + e_t \quad (9)$$

This equation expresses downstream prices as a product of upstream costs (both direct and related to the exchange rate) marked up for profits, i.e. a typical Cobb-Douglas function. This function assumes a constant percentage markup on upstream costs which could be either temporarily increased (if $e > 0$) or decreased (if $e < 0$). How the pricing equilibrium is restored following positive and negative disequilibria, defines whether the transmission if symmetric or not. When adjustment to positive disequilibria is slower than to negative ones, welfare-decreasing APT occurs.

Since all price series described above are integrated of the order one[8] we verify the presence of a long-run relationship using both linear and non-linear cointegration frameworks. For every equation, we estimate the Phillips-Perron Z_α test for cointegration under the null hypothesis of no cointegration, the long truncation parameter ($n/30$) and a constant.[9] We further verified the results using eigenvalue and trace tests. To ensure that ESTAR-type non-linearities is included in the analysis, the testing framework includes cointegration tests proposed by Kapetanios et al. (2006) which model the equilibrium process in a way that links the strength of the equilibrium attractor to the sign and size of the residual. This ensures that extremely non-linear cases that might have been excluded from the analysis by linear cointegration tests are included in the sample.

3.3 Testing for Non-linearities

The focus of the analysis is on the mean-reversion process analogous to (7), i.e. Dickey-Fuller approximation of the ECM mechanism. While those models represent the simplified picture of the price adjustment, inferior to that offered by fully-fledged ECM models in the tradition of Engle & Granger (1987) and Stock & Watson (1993), they have several advantages over them that make the simplification useful for our purposes.

Firstly, since we use k non-stationary variables (k equal to 2 or 3 depending on the presence of the exchange rate), accounting for upstream and downstream price dynamics causes a reduction in the number of degrees of freedom. As the tests based on the Taylor-expansion require fourth order approximation and n lags, the testing for non-linearities in the full-blown ECM would be based on the model with $[k + (n - 1) + 2 * n] * 5$ variables. This results in lower power of tests for non-linearities and potentially exclusion of short-sample transmissions. Simplified DF model requires only $[n + 1] * 5$ variables.

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[7]For USP-MSP transmission, we omit the exchange rate as both prices are denoted in USD.

[8]Detailed results of ADF tests for so many series would require a large amount of space, so the results of the tests are not reported here - they can be provided by the author on request.

[9]Z_α test is similar to typical ADF and Z_t tests, i.e. it is also based on residuals from level estimation. However it has slower rate of divergence and better small-sample properties, i.e. higher power - Phillips & Ouliaris (1990)

Secondly, from the practical point of view, the estimation of non-linear models boils down to multi-dimensional optimization problem. In the case of the fully-scaled ECM models, this optimization is computational burdensome and poses a number of practical issues, including incomparability between models with different set of variables (in particular USP-to-MSP and MSP-to-USP), and partially indefinite Hessians which prohibits calculation of standard errors of the parameters.

Last but not least, since the nature of the research requires that the results are easily comparable between tiers, countries and products, some parameters have to be brought to a common denominator - for example smoothing parameters in the STAR models and the thresholds in the models. While maintaining such a degree of uniformity would be difficult in the full ECM model, it is manageable in the DF simplification. As an example of such simplification consider expressing the smoothing parameter as a divisor of one residuals' standard deviation, so that only the quotient has to be estimated - as specified in Teräsvirta (1994).

Given the above, we estimated the following DF ECM model:

$$\begin{aligned} \Delta\hat{e}_t &= [1-G(\hat{e}_{t-d},\zeta,c)][\delta_0^L\hat{e}_{t-1}+\textstyle\sum_{i=1}^m\delta_i^L\Delta\hat{e}_{t-1}] \\ &\quad +G(\hat{e}_{t-d},\zeta,c)[\delta_0^H\hat{e}_{t-1}+\textstyle\sum_{i=1}^m\delta_i^H\Delta\hat{e}_{t-1}]+\nu_t \end{aligned} \tag{10}$$

When G is a logistic function, the model which has different adjustment speeds for negative and positive residuals, while the exponential function results in the same adjustment for extreme positive or negative residuals, but different adjustment for small and extreme values. Those two regimes are denoted H(igh) and L(ow) since when $G(\circ)=0$ adjustment is only δ_0^L, while when $G(\circ)=1$ the adjustment is $\delta_0^L+\delta_0^H$. For LSTAR models the low regime corresponds to $G=0$, i.e. significant negative disequilibria and shrunk margins. For ESTAR models the low regimes corresponds to small disequilibria. The sign of the coefficients in those regimes determines the nature and extent of non-linearities in price transmission and related per-unit welfare transfer.

To test for the adequacy of the above model over the simple DF linear model, following Escribano & Jordá (2001). Tables 2 and 3 present the results.[10]

3.4 Estimating the non-linear models

For all transmissions determined non-linear using the procedure by Teräsvirta (1994) we estimated (10). The results are summarized in Table 6. To facilitate the interpretation, below we analyse two sample STAR models (one with exponential and one with logistic transmission function).

3.4.1 Example of the ESTAR model

As a first example consider indirect crude oil-to-retail unleaded petrol price transmission for Cyprus. The results are summarized in Table 4 and should be interpreted as

[10] To facilitate comparisons, the results for tests applied to DSP-to-USP and MSP-to-USP transmissions are presented back-to-back, with L and E denoting LSTAR and ESTAR type of non-linearities (respectively) and $\times$ denoting cases when the null of linearity was not rejected.

Table 2: Non-Linearities in USP-to-DSP and MSP-to-DSP Transmission

	DIESEL	EURO	HGASOIL	LPG.1	RFO.1	RFO.2	SUPER
AT	× / ×	× / ×	× / ×	- / -	*E* / *L*	- / -	- / -
BE	*E* / *E*	*L* / *E*	× / *E*	× / ×	× / *L*	*L* / *E*	*E* / *L*
CY	× / ×	*E* / ×	*E* / ×	- / -	- / -	- / -	- / -
CZ	× / -	- / -	× / ×	- / *L*	- / -	- / -	- / -
DE	× / ×	× / *E*	*E* / *E*	- / -	*E* / *L*	- / -	*L* / ×
DK	*E* / ×	× / ×	*L* / *E*	- / -	× / ×	- / -	× / ×
EE	*E* / -	× / ×	- / -	- / -	- / -	- / -	- / -
ES	*E* / ×	× / *E*	*L* / *E*	× / -	× / ×	× / *E*	× / ×
FI	*E* / *E*	× / *L*	*E* / *E*	- / -	*E* / *L*	- / -	- / -
FR	*L* / *L*	× / *L*	*L* / *L*	× / ×	× / ×	× / ×	× / ×
GB	× / ×	*E* / ×	× / ×	- / -	× / ×	× / ×	- / -
GR	*L* / *L*	*E* / ×	× / *L*	- / -	× / ×	× / *E*	*L* / *L*
HU	- / ×	× / ×	- / ×	- / *L*	× / *E*	- / -	- / -
IE	*E* / *E*	× / ×	× / ×	- / -	- / -	× / *E*	× / ×
IT	× / ×	*E* / ×	*L* / ×	× / *L*	× / ×	× / ×	× / *L*
LT	× / ×	- / ×	× / *L*	- / ×	*L* / ×	- / ×	- / -
LU	*E* / *L*	*E* / *E*	*E* / ×	× / *L*	× / *L*	× / *E*	× / *E*
LV	- / -	× / -	- / -	- / -	- / -	- / -	× / -
MT	- / -	- / -	- / -	- / -	- / -	- / -	- / -
NL	*E* / *L*	× / ×	*E* / ×	*E* / *E*	*E* / *E*	- / -	× / ×
PL	× / ×	× / ×	× / ×	- / -	- / -	× / ×	- / -
PT	*E* / *E*	*E* / *E*	- / -	- / -	*E* / *E*	× / ×	*E* / *E*
SE	*L* / *L*	× / ×	*E* / *L*	- / -	*E* / *E*	- / -	- / -
SI	× / *L*	*E* / ×	- / ×	- / ×	- / -	- / -	- / -
SK	- / ×	- / ×	- / -	- / -	- / -	- / -	- / -

Table 3: USP to MSP Transmission - Nonlinearity Tests

Products	
DIESEL	ESTAR
EURO	
HGASOIL	
LPG.1	ESTAR
RFO.1	
RFO.2	
SUPER	

follows. The left half of the table identifies the transmission tier, product and country and presents the basic description of the model. The most important elements include:

- the smoothing parameter (ζ), which determine how dramatic is the switch from one adjustment regime to the other - the closer it is to zero the smoother the transition is. When the value of the parameter approaches ∞, the LSTAR model collapses to the SETAR model and ESTAR model collapses to the linear model;
- the delay for the transition value (d), which determines how responsive the adjustment is to lagged developments;
- the threshold value and the percentile of the threshold that identifies it in the sample (c and c^{th} respectively).[11] Those values determine the position of the transition function in the sample;
- the standard deviation of the residuals e_t;
- the percentage of observations on the transition variable for which the appropriate LSTAR / ESTAR functions yields values lower than .5, which defines the share of observation that are influenced by each regime.

The right half of the table summarizes the autoregressive portion of the piece-wise linear STAR model. The first column presents the direct estimates of the adjustment speed (i.e. the percentage of disequilibrium eliminated each term), and the remaining columns present the lagged explanatory variables, designed to capture the dynamics of the system. The results indicate that Cypriot crude-to-retail unleaded petrol price transmission is nonlinear, with the transition determined by the exponential function of the disequilibrium lagged by one period ($d = 1$) and centered around -0.01 (corresponding to the disequilibrium of 1%, which corresponds to the 45^{th} percentile). The lagged dynamics favoured by the AIC criterion include only the lagged disequilibrium level and no lagged autoregressive changes. The adjustment process is found to be strong for significant disequilibria (23% of disequilibrium eliminated, with the estimate significantly different from zero at 1%) but non-existing for small disequilibria, where the estimate of the cointegrating pull was found to be insignificantly different from zero at all significance levels. This finding corresponds to an adjustment model in which large positive and negative disequilibria are eliminated with equal strength, but small, insignificant disequilibria are left unchanged.

Figure 4 presents a graphical overview of the model. The first panel presents the transition function of the $\hat{e}_{t-d}$ with the observations marked as short vertical lines. The middle panel presents the $\hat{e}_t$ developments over time (black line and the left scale) and imposes the transition function on it (gray line and the right scale). The lowest panel presents simulated adjustment to the positive and negative shocks equal

[11] The percentiles were scaled around 0 by subtracting 0.5 from their values. For example, -0.051 stands for 0.449th percentile. This was done so as to facilitate testing and interpretation of the model - zero corresponds to median dis-equilibrium, which (by definition) equals zero.

Table 4: ESTAR Model of Adjustment for Cypriot EURO USP-to-DSP Transmission (Example)

Transition Country	Product Transition	ζ d	c c^{th}	$< 1/2$ $sd(\hat{u}_t)$	γ_1^L γ^H	ψ_1^L ψ_1^H	ψ_2^L ψ_2^H	ψ_3^L ψ_3^H	ψ_4^L ψ_4^H
USP→DSP	EURO	3.212	-0.01	0.312	-0.427				
CY	ESTAR	1	-0.051	0.065	-0.23***				

Table 5: LSTAR Model of Adjustment for Belgian EURO USP-to-DSP Transmission (Example)

Transition Country	Product Transition	ζ d	c c^{th}	$< 1/2$ $sd(\hat{u}_t)$	γ^L γ^H	ψ_1^L ψ_1^H	ψ_2^L ψ_2^H	ψ_3^L ψ_3^H	ψ_4^L ψ_4^H
USP→DSP	EURO	15.004	0.027	0.704	-0.335***	-0.172***			
BE	LSTAR	2	0.205	0.064	-0.204***	0.004			

two standard-deviations (respectively green and red). To facilitate comparisons the response to negative shocks was scaled by -1, and the difference between the two is presented as a blue line. Whenever the blue line is above the horizontal axes it denotes that a positive disequilibrium is eliminated slower than the negative one, so that the prices rise faster than they fall and the market participants protect artificially increased profits.

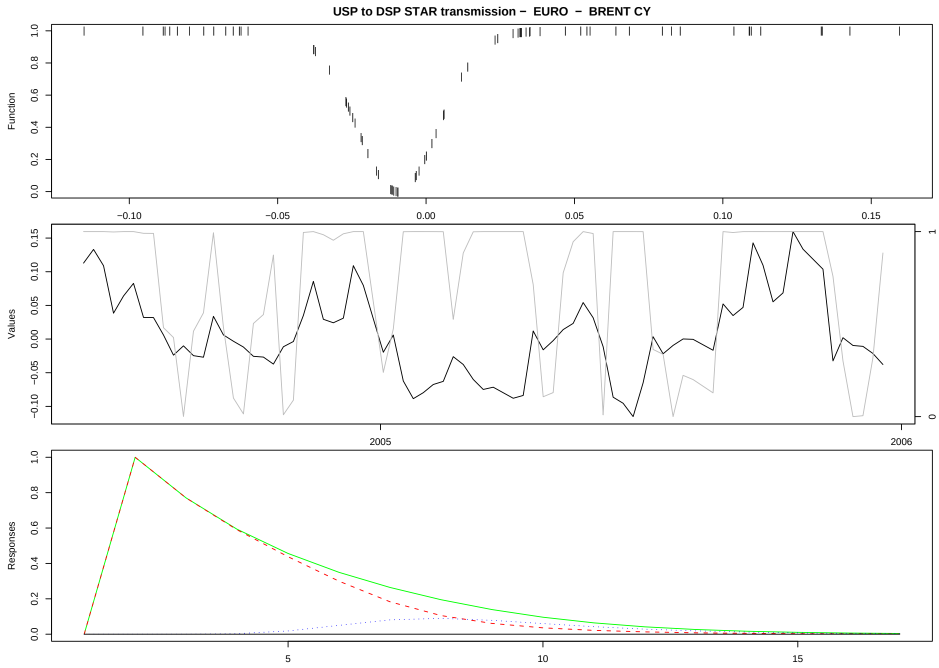
The results of the analysis point to an ESTAR model giving rise to moderate APT, as the positive disequilibria are eliminated more slowly than the negative ones. As opposed to the traditional SETAR models, the difference seems to be small.

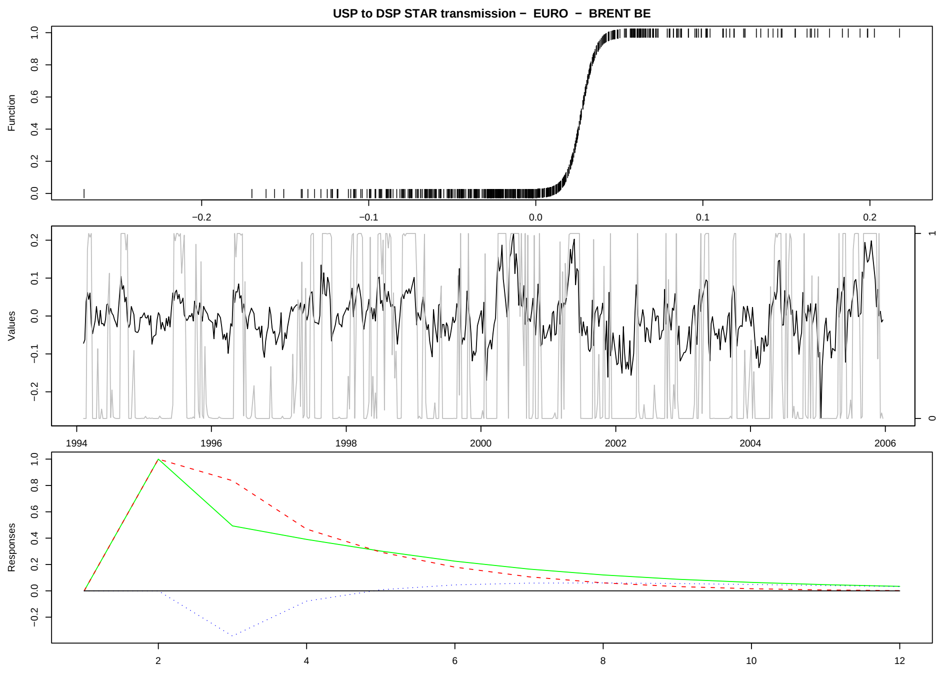
3.4.2 Example of the LSTAR model

As a second example, consider crude oil to retail unleaded petrol price transmission in Belgium. Table 5 summarizes the results of the estimation. The estimates indicate that the transmission is of LSTAR type that *could* give rise to APT with faster immediate adjustment for negative disequilibria (-.335) compared to the positive ones (-.204). However, one should notice the presence of the lagged LHS variable, which could affect the actual adjustment process. The results of the simulation of adjustment presented in Figure 4 shows that although the SR adjustment speeds for the LSTAR model suggest that negative disequilibria are eliminated faster than the positive ones, once the autoregressive elements are taken into account, the reverse is true. This should be seen as another innovative contribution of our analysis. Indeed, so far, researchers have focused on the values of the parameters, disregarding the necessity of checking for the end effect of adjustment e.g. via simulation of price adjustment. The results of our analysis show that the end result may be opposite to the ones assumed in the existing literature.

All other models summarized in Table 6 should be interpreted in a manner similar to the one described above.

Figure 4: Adjustments for Cypriot EURO USP-to-DSP ESTAR Transmission (left) and Belgian EURO USP-to-DSP Transmission LSTAR Transmission (right)





4 Discussion of the Results

4.1 Testing for the Presence of Non-linearities

The most striking pattern visible in the results is the widespread presence of exponential non-linearities (ESTAR), compared to those of logarithmic nature (LSTAR) which are similar to SETAR models commonly used in the applied literature. This result is only to be expected as the reasons for ESTAR-type non-linearities (e.g. adjustment costs, market frictions, and such) are more likely to occur than those responsible for LSTAR-type non-linearities (e.g. market collusion). This implies that by constraining the nature and shape of asymmetries to SETAR models, the previous studies misrepresented the nature of asymmetries and, as a result, their potential causes and effects.

The results indicate that:

- the presence of non-linearities is persistent across tiers - out of 43 cases on non-linearities found in USP-to-DSP transmission, 26 had the counterparts in the direct MSP-to-DSP transmission;
- for the cases when non-linearities were identified only for one stage, the other stage was usually found not to be cointegrated (the cases with mixed results are mostly constrained by short samples);
- the nature of non-linearities is largely consistent across tiers - in 18 cases the same type of non-linearities was identified on both stages.

The results indicate that the non-linearities are widespread between markets, products and tiers. The following patterns are visible:

- with respect to transmission tiers:
  - non-linearities concentrate downstream - there is a slightly higher percentage of non-linear cases in the MSP-to-DSP transmission - 50 out of 175, compared with 43 out of 175 for the indirect USP-to-DSP and 2 out of 7 for the USP-to-MSP transmission;
  - potentially welfare-decreasing non-linearities (LSTAR) are more widespread than ESTAR at the retail level (24 out of 50 in the case of MSP-to-DSP transmission compared to 12 out of 43 for the indirect transmission);
- with respect to products:
  - non-linearities are particularly common in the retail products - unleaded and leaded petrol, diesel and gasoil,
  - products usually purchased by companies (fuel oils) exhibit fewer non-linearities;
  - LPG again stands out in terms of results, with no signs of non-linearities in the indirect (from crude oil) transmission and non-linearities in the direct (from wholesale) transmission;

- with respect to national markets - the non-linearities spread fairly evenly across countries, with the exception of Eastern Europe, which might be due to the different time span of the sample.

Our results regarding the presence of non-linearities confirm results from the literature. In particular, the results support the non-linearities found in the crude-to-unleaded petrol transmission in the UK (Reilly & Witt (1998), Eltony (1998), Galeotti et al. (2003), Wlazlowski (2003), Driffield et al. (2003), Grasso & Manera (2007), Hosken et al. (2007, p. 2)), crude-to-leaded petrol in Germany (Kirchgassner & Kubler (1992)), wholesale-to-retail in Germany and France (Grasso & Manera (2007)), crude-to-unleaded petrol in Spain (Contin et al. (2004)), crude-to-unleaded petrol in Italy (Berardi et al. (2000) and Galeotti et al. (2003)).

Furthermore, these results support the results of the studies that *failed* to find non-linearities in price adjustment, e.g. in the wholesale-to-unleaded petrol transmission in the Netherlands (Bettendorf et al. (2003)), in the crude-to-leaded petrol in Italy (Berardi et al. (2000)), in the crude-to-retail and in the wholesale-to-retail and crude-to-wholesale transmissions for Spain, France and Germany (Galeotti et al. (2003)).

The most significant departure from the literature is the failure to reject the null of spurious regression in the crude-to-retail leaded petrol transmission for the UK. Both Bacon (1991) and Manning (1991) found this transmission to be asymmetric, but they were using a significantly different sample (covering data from the 1970s and 1980s), and without testing for cointegration.

4.2 Estimation of Non-linearities

The most visible patterns in the results are:

- the estimates of all models - both exponential and logistic - are coherent and consistent with the theory of non-linear cointegration. The crucial elements are the following:
  - the LSTAR models have highly significant negative coefficients on lagged-residuals (γ^L and γ^H), confirming that equilibrium is restored after an exogenous shock;
  - the ESTAR models have highly significant negative coefficients in the outer regime (i.e. one for significant residuals - γ^H) and insignificant in the middle regime (γ^L);
  - the parameters responsible for non-linear behaviour indicate smooth regime change and do not support previously taken assumptions of sudden and full regime change (as implied by SETAR models);
  - all pricing regimes are represented (as shown by the percentage of observations for which the transition function is lower than .5);
  - the threshold value is well centered around the median disequilibrium (50^{th} percentile, centered around zero in the Table 6);

- autoregressive dynamics (i.e. parameters ψ^H and ψ^L) are well represented and significantly affect the adjustment process;

- with respect to cross-tier comparisons:
  - MSP-to-DSP transmission is generally faster to adjust back to the equilibrium and exhibits a greater degree of non-linearity;
  - MSP-to-DSP transmission parameters indicate more abrupt regime transition, with higher smoothing parameters and lower percentage of observations below the 50% threshold;
  - MSP-to-DSP transmission exhibits richer dynamics than USP-to-DSP indirect transmission, yet the γ estimates are more consistent and exhibit lower variance. This is understandable, as MSP-to-DSP transmission is spared the influence of the refining stage;

- with respect to cross-product comparisons:
  - consumer products (leaded petrol and DIESEL) exhibit more homogeneous estimates and higher degree of non-linearity than the industry products (fuel oils and gasoil) both in ESTAR and LSTAR models. This might support Johnson (2002) who indicates differences between pricing of products targeted for different clients;
  - LPG and leaded petrol estimates are extremely diversified;

- with respect to cross-country comparisons:
  - the degree of non-linearities is actually greater in the peripheral countries than in the core old EU-15 countries. The most significant outliers are located in the Iberian and Scandinavian Peninsulas (Portugal and Spain, Finland and Sweden). This could be a result of transportation problems or more likely to the impact of different sources of crude oil - see Wlazlowski (2007) and maps herein;
  - the possible link between volatility and APT reported by Asplund et al. (2000) does not seem to be confirmed by the results as high-volatility countries and markets do not appear to be more likely to exhibit APT.

5 Conclusions

Asymmetric nature of responses of downstream petroleum product prices to upstream cost changes can potentially result in a significant welfare transfer. Recently, attention paid to those issues greatly increased, as crude oil prices soar following tight supply and ever-growing demand.

Although the issues of asymmetric price transmission are addressed in the literature, the framework applied for that purpose suffers from rigid and unrealistic assumptions. In this article we re-visit the price transmission in the EU, utilizing a multi-product, -country and -tier dataset with the help of smooth transition models.

The new framework allows for easier testing for the presence of non-linearities in price transmission and can be used to analyse its nature.

The results of tests for the presence and nature of non-linearities indicate that the majority of non-linear adjustment processes is of an exponential nature. This implies that the commonly used SETAR models mis-specify the nature of the adjustment. For the remaining cases the results of the analysis favours the LSTAR model which is an enhanced, smooth-transition version of the old SETAR models. This indicates that the traditional view of non-linearities as welfare-decreasing, two-regime pricing behaviour (assumed in SETAR and LSTAR models) might have to be reconsidered in favour of the one that distinguishes between small and large disequilibria - as in the ESTAR model.

Based on the results of tests for the presence and the character of the non-linearities, we estimated the non-linear models for price transmission. The results encompass the existing literature, but also indicate that the degree of welfare-decreasing APT might be lower than expected once more complex autoregressive adjustment dynamics are taken into account. This finding shows that the previous studies while correct in the assessment of the presence of non-linearities might have overlooked the actual impact they have on the market.

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APPENDIX

Table 6: STAR DF ECM Estimation (Brent) - Results

Transition Country	Product Transition	ζ d	c c^{th}	$< 1/2$ $sd(\hat{u_t})$	γ_1^L γ^H	ψ_1^L ψ_1^H	ψ_2^L ψ_2^H	ψ_3^L ψ_3^H	ψ_4^L ψ_4^H
USP→DSP	EURO	15.004	0.027	0.704	-0.335***	-0.172***			
BE	LSTAR	2	0.205	0.064	-0.204***	0.004			
USP→DSP	EURO	3.212	-0.01	0.312	-0.427				
CY	ESTAR	1	-0.051	0.065	-0.23***				
USP→DSP	EURO	9.401***	-0.029	0.079	0.493*	0.129			
GB	ESTAR	1	-0.091	0.1	-0.091***	0.07			
USP→DSP	EURO	3.148	0.036	0.186	-0.116		0.061		
GR	ESTAR	1	0.18	0.079	-0.124***		-0.173***		
USP→DSP	EURO	2.498^{+}	0.011	0.293	-0.169				
IT	ESTAR	1	0.094	0.057	-0.151***				
USP→DSP	EURO	4.552	-0.061	0.096	-0.022	-0.343			
LU	ESTAR	1	-0.32	0.069	-0.193***	-0.044			
USP→DSP	EURO	1.512***	-0.026	0.477	-0.13*	-0.041			-0.211**
PT	ESTAR	2	-0.068	0.128	-0.08***	0.146**			0.296***
USP→DSP	EURO	1.312***	0.008	0.39	0.819*	-0.116	0.661**		
SI	ESTAR	1	0.084	0.073	-0.542***	0.53***	0.176		
USP→DSP	DIESEL	1.525	0.053	0.306	-0.066	-0.092	0.101		
BE	ESTAR	3	0.287	0.071	-0.183***	-0.306***	-0.187***		
USP→DSP	DIESEL	5.891^{+}	-0.013	0.112	-0.053	-0.495	-0.191	0.084	
DK	ESTAR	2	-0.077	0.068	-0.137***	-0.208***	-0.088*	-0.107**	
USP→DSP	DIESEL	4.276**	-0.001	0.184	-3.244	3.307		-0.238	
EE	ESTAR	2	-0.023	0.081	-0.268***	0.338***		0.261**	
USP→DSP	DIESEL	1.523***	0.025	0.329	-0.031	0.14			0.055
ES	ESTAR	2	0.17	0.077	-0.136***	-0.251***			0.077
USP→DSP	DIESEL	5.823***	-0.004	0.099	2.756**	-0.169			
FI	ESTAR	1	0.032	0.075	-0.156***	-0.101**			
USP→DSP	DIESEL	8.075	-0.042	0.294	-0.184***				-0.008
FR	LSTAR	1	-0.206	0.074	-0.143***				0.084*
USP→DSP	DIESEL	50	0.013	0.589	-0.148***	0.009	-0.121**	-0.016	
GR	LSTAR	2	0.089	0.091	-0.11***	-0.271***	-0.159**	-0.133**	
USP→DSP	DIESEL	3.523	0.007	0.208	-0.079	0.203	0.359		0.171
IE	ESTAR	2	0.052	0.094	-0.093***	0.044	0.002		0.053
USP→DSP	DIESEL	2.049^{+}	0.006	0.32	0.367***	-0.233***	-0.175*	0.005	
LU	ESTAR	1	0.085	0.07	-0.199***	-0.021	-0.025	-0.099*	
USP→DSP	DIESEL	4.376***	-0.036	0.112	0.246	-0.469***	-0.196		
NL	ESTAR	1	-0.189	0.064	-0.148***	-0.109**	-0.056		
USP→DSP	DIESEL	3.223***	0.013	0.191	-0.271	0.743**	0.007		
PT	ESTAR	2	0.074	0.11	-0.079***	0.003	0.089*		
USP→DSP	DIESEL	5^{+}	-0.075	0.274	-0.06**	-0.255**	-0.009	-0.035	
SE	LSTAR	2	-0.226	0.112	-0.086***	-0.067	-0.146***	-0.154***	
USP→DSP	HGASOIL	2.016*	0.045	0.312	0.125				
CY	ESTAR	1	0.195	0.066	-0.309***				
USP→DSP	HGASOIL	1.716*	-0.074	0.246	-0.144**	-0.278**			
DE	ESTAR	2	-0.365	0.07	-0.146***	-0.114**			
USP→DSP	HGASOIL	1.03^{+}	0.012	0.594	-0.126***	-0.304***	-0.091	0.147^{+}	
DK	LSTAR	2	0.093	0.083	-0.064^{+}	-0.202**	-0.07	-0.318^{+}	
USP→DSP	HGASOIL	2.002^{+}	0.023	0.666	-0.168***	-0.121^{+}			
ES	LSTAR	1	0.167	0.082	-0.146***	-0.006^{+}			
USP→DSP	HGASOIL	3.271	0.003	0.205	-0.499	0.018	-0.072	0.008	
FI	ESTAR	1	0.032	0.079	-0.129***	-0.231***	-0.083	-0.095*	
USP→DSP	HGASOIL	1.429	0.02	0.637	-0.074**	-0.307***		-0.11	
FR	LSTAR	1	0.137	0.072	-0.128***	0.123		0.023	
USP→DSP	HGASOIL	5.514	0.057	0.773	-0.074***	-0.157***			
IT	LSTAR	1	0.273	0.084	-0.087***	0.139			
USP→DSP	HGASOIL	2.86**	0.024	0.207	-0.026	-0.394***	-0.225**	0.039	
LU	ESTAR	1	0.167	0.066	-0.208***	-0.064	-0.047	-0.137***	
USP→DSP	HGASOIL	1.562***	-0.004	0.425	0.156	-0.425***	-0.107		
NL	ESTAR	1	0.05	0.071	-0.184***	0.067	-0.035		
USP→DSP	HGASOIL	4.479**	-0.016	0.154	0.219		0.165		
SE	ESTAR	2	-0.052	0.08	-0.136***		-0.145***		
USP→DSP	RFO.1	6^{+}	-0.078	0.081	-0.044				

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Table 6 – continued from previous page

Transition Country	Product Transition	ζ d	c c^{th}	$< 1/2$ $sd(\hat{u}_t)$	γ_1^L γ^H	ψ_1^L ψ_1^H	ψ_2^L ψ_2^H	ψ_3^L ψ_3^H	ψ_4^L ψ_4^H
AT	ESTAR	1	-0.23	0.116	-0.09***				
USP→DSP	RFO.1	1.468**	-0.03	0.415	-0.043	0.133			
DE	ESTAR	1	-0.084	0.1	-0.093***	-0.278***			
USP→DSP	RFO.1	2.407***	-0.195	0.077	0.071	0.153	-0.13	-0.016	
FI	ESTAR	1	-0.421	0.135	-0.123***	-0.248***	-0.125**	-0.147***	
USP→DSP	RFO.1	50	0.094	0.753	-0.805***				
LT	LSTAR	1	0.258	0.143	-0.701***				
USP→DSP	RFO.1	3.599***	0.027	0.194	-0.291		-0.104		
NL	ESTAR	1	0.127	0.092	-0.124***		0.103**		
USP→DSP	RFO.1	5.484	0.074	0.098	0.056				-0.034
PT	ESTAR	1	0.212	0.124	-0.07***				-0.07
USP→DSP	RFO.1	3.999	0.006	0.176	-0.209	-0.027			-0.248
SE	ESTAR	1	0.016	0.112	-0.185***	-0.139***			0.131***
USP→DSP	RFO.2	8^{+}	0.01	0.616	-0.207**				
BE	LSTAR	1	0.117	0.057	-0.301***				
USP→DSP	LPG.1	13.04***	-0.007	0.066	2.365*	0.554*	0.498	0.56	
NL	ESTAR	1	0.022	0.073	-0.105***	0.191***	-0.13**	0.088	
USP→DSP	SUPER	11.999	0.037	0.071	-0.443*	-0.324			0.039
BE	ESTAR	1	0.241	0.073	-0.155***	-0.119**			-0.096**
USP→DSP	SUPER	4.596	0.05	0.862	-0.58***				0.134
DE	LSTAR	1	0.368	0.047	-0.231**				0.076
USP→DSP	SUPER	50	-0.091	0.17	-0.207***	-0.286***	-0.054	-0.193*	
GR	LSTAR	2	-0.331	0.089	-0.066***	-0.034	-0.126***	-0.041	
USP→DSP	SUPER	2.854***	-0.036	0.31	-0.337*	0.613***			-0.134
PT	ESTAR	1	-0.155	0.162	-0.093***	0.123**			0.321***
MSP→DSP	EURO	6.497	0.026	0.09	-0.005	0.009	-0.119		
BE	ESTAR	1	0.208	0.05	-0.398***	-0.245***	-0.155***		
MSP→DSP	EURO	2.868^{+}	-0.04	0.203	-0.25	-0.435***	-0.101	-0.032	0.126*
DE	ESTAR	3	-0.276	0.06	-0.229***	-0.311***	-0.271***	-0.134**	-0.151***
MSP→DSP	EURO	5.416*	-0.003	0.105	0.644	-0.675	-0.106		
ES	ESTAR	2	-0.004	0.05	-0.206***	-0.142***	-0.129***		
MSP→DSP	EURO	4.5	0.027	0.625	-0.22***			0.102*	
FI	LSTAR	1	0.125	0.075	-0.254***			0.063	
MSP→DSP	EURO	11.001^{+}	0.017	0.632	-0.202***	-0.065	-0.053		
FR	LSTAR	3	0.131	0.055	-0.288***	-0.104*	-0.22***		
MSP→DSP	EURO	4.981**	0.017	0.127	0.031	0.203	0.088		0.038
LU	ESTAR	1	0.145	0.047	-0.32***	-0.179***	-0.174***		-0.091*
MSP→DSP	EURO	2.495***	0.006	0.265	-0.002				-0.223*
PT	ESTAR	1	0.051	0.131	-0.081***				0.205***
MSP→DSP	DIESEL	2.022^{+}	-0.024	0.268	0.124	-0.568^{+}	-0.551^{+}	-0.336^{+}	-0.193**
BE	ESTAR	1	-0.201	0.056	-0.243***	-0.323***	-0.156***	-0.007	-0.007^{+}
MSP→DSP	DIESEL	1.376***	0.039	0.341	-0.101	-0.542***	-0.178*		
FI	ESTAR	1	0.248	0.064	-0.189***	-0.025	-0.078		
MSP→DSP	DIESEL	7.004	-0.02	0.363	-0.308***	-0.126	-0.001		
FR	LSTAR	3	-0.138	0.05	-0.244***	-0.123	-0.153*		
MSP→DSP	DIESEL	32.359	-0.035	0.345	-0.178***	0.011	-0.353***	-0.051	
GR	LSTAR	4	-0.155	0.072	-0.174***	-0.273***	-0.157***	-0.054	
MSP→DSP	DIESEL	10.788**	0	0.112	-1.747	-0.059			-0.202
IE	ESTAR	1	0.003	0.093	-0.108***	0.104**			0.166***
MSP→DSP	DIESEL	6.412	0.041	0.808	-0.388***	-0.043	-0.04	-0.052	
LU	LSTAR	2	0.307	0.053	-0.12*	-0.241**	-0.317***	-0.076	
MSP→DSP	DIESEL	7.02	-0.013	0.405	-0.234***	-0.412***	-0.199**	-0.13	-0.014
NL	LSTAR	3	-0.096	0.044	-0.08*	-0.392***	-0.343***	-0.082	-0.172***
MSP→DSP	DIESEL	7.001^{+}	0.026	0.095	0.222^{+}				
PT	ESTAR	1	0.127	0.104	-0.073***				
MSP→DSP	DIESEL	1.965^{+}	-0.012	0.458	-0.057**	-0.259***	-0.064^{+}	0.092***	
SE	LSTAR	2	-0.043	0.114	-0.08***	-0.09	-0.152^{+}	-0.258***	
MSP→DSP	DIESEL	13.787	-0.046	0.273	-0.382**	0.272	0.884***		
SI	LSTAR	2	-0.231	0.066	-0.581***	0.363***	0.075		
MSP→DSP	HGASOIL	4.009^{+}	-0.037	0.153	-0.43***	-0.01	0.012	-0.025	
BE	ESTAR	1	-0.283	0.054	-0.226***	-0.409***	-0.284***	-0.134***	
MSP→DSP	HGASOIL	3.096***	0.025	0.176	-0.516***	0.159	0.158	-0.317**	-0.147
DE	ESTAR	2	0.258	0.042	-0.196***	-0.468***	-0.324***	-0.107*	-0.127***
MSP→DSP	HGASOIL	2.713***	-0.022	0.258	0.081	-0.844***	-0.73***	-0.631**	0.014
DK	ESTAR	4	-0.062	0.064	-0.09***	-0.36***	-0.148**	-0.053	-0.12**
MSP→DSP	HGASOIL	4.746***	0.036	0.107	-0.541**	0.044	0.269	-0.098	-0.083
ES	ESTAR	2	0.259	0.065	-0.159***	-0.078	-0.206***	-0.069	-0.06

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Table 6 – continued from previous page

Transition	Product	ζ	c	$< 1/2$	γ_1^L	ψ_1^L	ψ_2^L	ψ_3^L	ψ_4^L
Country	Transition	d	c^{th}	$sd(\hat{u}_t)$	γ^H	ψ_1^H	ψ_2^H	ψ_3^H	ψ_4^H
MSP→DSP	HGASOIL	3.933***	0.026	0.171	-0.068	-0.399*	0.216		
FI	ESTAR	1	0.201	0.057	-0.252***	-0.161***	-0.111**		
MSP→DSP	HGASOIL	6	0.005	0.554	-0.158***	-0.32***	-0.091	-0.023	-0.041
FR	LSTAR	3	0.054	0.05	-0.124***	-0.187***	-0.16**	-0.133*	-0.13**
MSP→DSP	HGASOIL	32.447	-0.043	0.325	-0.229***	-0.098	-0.314***		
GR	LSTAR	2	-0.175	0.093	-0.101***	-0.153***	-0.143***		
MSP→DSP	HGASOIL	24.153	0.057	0.857	-0.437***		-0.083		
LT	LSTAR	3	0.36	0.053	-0.921***		-0.626*		
MSP→DSP	HGASOIL	2.401	-0.02	0.358	-0.182***		-0.099		
SE	LSTAR	1	-0.141	0.07	-0.169***		-0.052		
MSP→DSP	RFO.1	15^{+}	0.069	0.784	-0.081***		-0.22***		
AT	LSTAR	3	0.285	0.096	-0.229***		0.091		
MSP→DSP	RFO.1	7.599^{+}	-0.036	0.197	-0.447***	-0.335***			
BE	LSTAR	1	-0.304	0.043	-0.615***	-0.038			
MSP→DSP	RFO.1	4.793^{+}	0.026	0.694	-0.297***	-0.201***	-0.175***		
DE	LSTAR	1	0.195	0.062	-0.237***	0.034	0.094		
MSP→DSP	RFO.1	8.998^{+}	0.034	0.598	-0.103***	-0.176***			
FI	LSTAR	1	0.098	0.13	-0.118***	-0.263***			
MSP→DSP	RFO.1	10.401*	-0.005	0.117	5.882				0.189
HU	ESTAR	1	-0.003	0.082	-0.708***				0.152
MSP→DSP	RFO.1	50	-0.012	0.452	-0.087**		-0.106	0	
LU	LSTAR	1	-0.048	0.085	-0.144***		-0.083	-0.126**	
MSP→DSP	RFO.1	3.007**	0.08	0.091	0.026	-0.307*			
NL	ESTAR	1	0.386	0.068	-0.203***	-0.099**			
MSP→DSP	RFO.1	3.55**	-0.009	0.174	-0.149	0.62			
PT	ESTAR	2	-0.005	0.116	-0.096***	0.022			
MSP→DSP	RFO.1	2.021	-0.146	0.152	-0.082	0.111			
SE	ESTAR	1	-0.378	0.132	-0.148***	-0.164			
MSP→DSP	RFO.2	1.493*	-0.063	0.26	-0.312				
BE	ESTAR	1	-0.45	0.054	-0.478***				
MSP→DSP	RFO.2	6.542***	0.003	0.119	2.106	-0.138			
ES	ESTAR	1	0.058	0.065	-0.319***	0.121**			
MSP→DSP	RFO.2	0.995***	0.004	0.537	-0.04		-0.19***	-0.152**	-0.03
GR	ESTAR	2	0.026	0.088	-0.306***		0.064	0.07	-0.098
MSP→DSP	RFO.2	5.075*	0.018	0.117	0.034	-0.302			
IE	ESTAR	2	0.036	0.143	-0.106***	0.116***			
MSP→DSP	RFO.2	2.992^{+}	-0.001	0.294	0.627***		0.07	-0.065^{+}	
LU	ESTAR	1	-0.033	0.078	-0.283***		0.138*	0.212**	
MSP→DSP	LPG.1	50	-0.006	0.468	-0.046	0.193		0.044	
CZ	LSTAR	2	-0.028	0.057	-0.111**	0.355**		0.461**	
MSP→DSP	LPG.1	5.215	0.04	0.844	-0.343***	0.43***	0.482***		
HU	LSTAR	3	0.35	0.042	-0.215**	0.071	-0.001		
MSP→DSP	LPG.1	8.919	-0.03	0.21	-0.141***	-0.104		0.179	
IT	LSTAR	2	-0.289	0.045	-0.064**	0.343***		0.047	
MSP→DSP	LPG.1	16.001	-0.028	0.215	-0.34***		-0.163		
LU	LSTAR	1	-0.285	0.039	-0.294***		0.181***		
MSP→DSP	LPG.1	4.115***	0.002	0.183	-1.522	0.118	0.132		
NL	ESTAR	1	0.013	0.042	-0.248***	0.176**	-0.236***		
MSP→DSP	SUPER	12^{+}	-0.001	0.449	-0.107**	-0.243***	-0.18***		-0.209***
BE	LSTAR	1	-0.051	0.066	-0.22***	-0.409***	-0.179***		-0.018
MSP→DSP	SUPER	7.791	-0.057	0.277	-0.13***	0.095	-0.29***	-0.069	0.02
GR	LSTAR	1	-0.224	0.089	-0.069**	-0.331***	-0.226***	-0.044	-0.142***
MSP→DSP	SUPER	15.274	-0.01	0.393	-0.15***		0.056		
IT	LSTAR	3	-0.107	0.044	-0.168***		-0.175**		
MSP→DSP	SUPER	1.804***	0.001	0.346	0.74*				
LU	ESTAR	1	-0.067	0.042	-0.263***				
MSP→DSP	SUPER	2.517*	-0.025	0.317	-0.128	0.257			-0.377*
PT	ESTAR	1	-0.032	0.171	-0.088***	0.107			0.368***
USP→MSP	DIESEL	6.096	-0.008	0.103	-0.9	-0.449			
	ESTAR	1	-0.017	0.075	-0.228***	-0.089*			
USP→MSP	LPG.1	5.44**	0.066	0.112	-0.131	-0.094		0.336**	
	ESTAR	2	0.177	0.179	-0.094***	0.298***		0.06	