Article:

Shin, Yongcheol and Greenwood-Nimmo, Matthew (2013) Taxation and the asymmetric adjustment of selected retail energy prices in the UK. Economics Letters. pp. 411-416. ISSN 0165-1765

https://doi.org/10.1016/j.econlet.2013.09.020

Accepted Manuscript

Taxation and the asymmetric adjustment of selected retail energy prices in the UK

Matthew Greenwood-Nimmo, Yongcheol Shin

PII: S0165-1765(13)00427-8
DOI: http://dx.doi.org/10.1016/j.econlet.2013.09.020
Reference: ECOLET 6077

To appear in: *Economics Letters*

Received date: 14 June 2013
Revised date: 13 September 2013
Accepted date: 16 September 2013

Please cite this article as: Greenwood-Nimmo, M., Shin, Y., Taxation and the asymmetric adjustment of selected retail energy prices in the UK. *Economics Letters* (2013), http://dx.doi.org/10.1016/j.econlet.2013.09.020

*Highlights (for review)

- We study the price adjustment of 4 petroleum products in the UK following crude oil price changes
- We use the Nonlinear ARDL model to capture both short- and long-run asymmetries
- We find that pre-tax prices generally adjust more rapidly upwards than downwards
- Asymmetry is largely obscured at the pump where prices include both VAT and duty
- This raises the possibility that firms can use the tax system to conceal rent seeking behaviour

JEL Classifications: C22, H23, Q40.

Taxation and the Asymmetric Adjustment of Selected Retail Energy Prices in the UK

Matthew Greenwood-Nimmo[a], Yongcheol Shin[b,*]

[a] *Department of Economics, University of Melbourne, 111 Barry Street, Melbourne, VIC 3053, Australia.*
[b] *Department of Economics and Related Studies, University of York, Heslington, York, YO10 5DD, UK.*

Abstract

This paper investigates the adjustment of the prices of four key petroleum products in the UK following changes in the price of crude oil. We find significant evidence that the pre-tax prices of diesel, kerosene and gas oil adjust more rapidly in an upward than a downward direction but that the pre-tax price of unleaded petrol adjusts symmetrically. However, these patterns are obscured at the pump once one accounts for fuel duty and value added tax, raising the possibility that firms can use the tax system to conceal rent seeking behaviour.
Keywords: Nonlinear ARDL (NARDL), Asymmetric Gasoline Price Adjustment, Rockets and Feathers Hypothesis.

1. Introduction

A large literature has considered the issue of asymmetric price transmission (APT) from crude oil markets to retail gasoline markets. Specifically, gasoline prices may react asymmetrically to changes in the price of crude oil, which is the key upstream input into gasoline production; an authoritative survey is provided by Grasso and Manera (2007). A number of studies have found that retail gasoline prices rise more quickly following an increase in the market price of crude oil than they would fall following an equivalent decrease. This

*Corresponding author. Tel.: +44 (0)1904-433-757.
Email addresses: `matthew.greenwood@unimelb.edu.au` (Matthew Greenwood-Nimmo), `yongcheol.shin@york.ac.uk` (Yongcheol Shin)

phenomenon has come to be referred to as the *rockets and feathers* hypothesis following the early contribution of Bacon (1991).[1] The purpose of that paper was to empirically test the contention examined informally by the UK Monopolies and Mergers Commission that upward price adjustment is more rapid than downward adjustment, leading to periods in which firms can earn excess profit. By employing an asymmetric partial adjustment model assuming a quadratic adjustment process, Bacon finds evidence in support of the hypothesised asymmetry. A number of studies have since considered the same issue with mixed results. A notable contribution in support was made by Borenstein, Cameron and Gilbert (1997, BCG), who employ a hybrid error correction model where changes in gasoline and oil prices are decomposed into positive and negative changes. However, their results have been disputed by Bachmeier and Griffin (2003) on the grounds that BCG study low frequency data and that they employ a 'nonstandard estimation methodology'.

A closely related strand of literature has considered asymmetric pass-through of the exchange rate to retail energy prices, reflecting the convention of quoting oil prices in US$ per barrel (US$/bbl). Using a simple asymmetric ECM, Reilly and Witt (1998) find that a Sterling depreciation is rapidly passed through to higher prices at the pump but that a strengthening of the Pound is not met by a commensurate reduction in retail prices. Similarly, Asplund, Eriksson and Friberg (2000) find that Swedish retail gasoline prices react more swiftly to the exchange rate than to the crude oil price while Galeotti, Lanza and Manera (2003) find further evidence that the speed of equilibrium correction is asymmetric with respect to both oil price and exchange rate shocks.

The literature surveyed above has two general shortcomings. Firstly, most of the existing studies have employed the two-step Engle-Granger approach to estimating single-equation ECMs. However, it is well-established that single-step fully dynamic ARDL estimation is more efficient and yields improved performance as it does not suffer from any estimation uncertainty or errors arising from estimation of the long-run cointegrating relation in a

[1]Various theoretical explanations for asymmetric price adjustment have been proposed in the literature, the dominant three being oligopolistic pricing behaviour (Radchenko, 2005), inventory capacity and costs (Borenstein and Shepard, 2002) and nonlinear consumer search-effort (Johnson, 2002).

separate first step (Banerjee, Dolado, Galbraith and Hendry, 1993; Banerjee, Dolado and Mestre, 1998; Pesaran, Shin and Smith, 2001).[2] Secondly, the majority of papers consider only short-run dynamic asymmetries and abstract from potential long-run nonlinearity. This may be a plausible simplification in a competitive market setting, but in general it should be tested rather than assumed. Indeed, using a modified version of BCG's framework to analyse both short- and long-run asymmetries in upstream and downstream energy prices, Balke, Brown, and Yücel (1998, BBY) document 'pervasive and large' asymmetries. This is a potentially significant observation, as Shin, Yu and Greenwood-Nimmo (2013, SYG) demonstrate that estimation of the model dynamics will be profoundly compromised when a nonlinear long-run relationship is mis-specified as linear.

In this paper, we revisit the question of APT in UK retail energy markets using the Nonlinear ARDL approach developed by SYG. This represents a simple and innovative asymmetric framework which combines single-step estimation with the capacity to accommodate both long-run and dynamic asymmetries by exploiting partial sum decompositions of the explanatory variable.[3] Using the NARDL framework, we consider APT from crude oil price changes to the retail prices of four major petroleum products in the UK over the period January 1999 – March 2013. Our results indicate that the long-run relationship is either linear or only mildly asymmetric in all cases, indicating that retailers have generally passed cost changes on to consumers approximately symmetrically in the long-run. However, the speed of upward adjustment exceeds that of downward adjustment for derv, kerosene and gas oil (aka red diesel) indicating a degree of downward price-stickiness consistent with the rockets and feathers hypothesis. Our results are suggestive of a similar effect in the case of unleaded petrol although the asymmetry is not statistically significant. Lastly, we show that consumers who observe the pump price including tax and duty will only perceive asym-

[2] Another strand of the literature has analysed price transmission using the more efficient vector error correction modelling framework. However, existing system models are not well suited to the joint analysis of short- and long-run asymmetries in the relationship between the crude oil price and the prices of refined petroleum products, which is our main interest here. We therefore confine our attention to the single equation case where such asymmetries can be readily accommodated.

[3] Partial sum decompositions are employed by both BCG and BBY. However, they employ hybrid specifications that bear as much similarity to the hidden cointegration approach (e.g. Hornavar, 2009) as to ours.

metry in the case of kerosene where the tax/duty component is the lowest. This raises an important antitrust issue as it suggests that oligopolistically competitive firms may exploit UK tax legislation to conceal rent-seeking behaviour. This poses a challenge to regulators who must monitor the interplay between pre- and post-tax prices as well as to policymakers charged with the design and implementation of the system of fuel taxation.

2. The Nonlinear ARDL Model

The NARDL model proposed by SYG is among the simplest in the class of nonlinear error correction models. It has the desirable attributes that it is linear in parameters, it is readily estimable by OLS and it can accommodate combinations of persistent and stationary variables in a coherent manner. The model is built around an asymmetric long-run relationship of the form:

$$y_t = \boldsymbol{\beta}^{+\prime}\boldsymbol{x}_t^+ + \boldsymbol{\beta}^{-\prime}\boldsymbol{x}_t^- + u_t, \quad \Delta\boldsymbol{x}_t = \boldsymbol{v}_t, \tag{2.1}$$

where y_t is a scalar I(1) variable, $\boldsymbol{x}_t$ is a $k \times 1$ vector of regressors defined such that $\boldsymbol{x}_t = \boldsymbol{x}_0 + \boldsymbol{x}_t^+ + \boldsymbol{x}_t^-$ where $\boldsymbol{x}_0$ is the initial value and where $\boldsymbol{x}_t^+ = \sum_{j=1}^t \Delta\boldsymbol{x}_j^+ = \sum_{j=1}^t \max(\Delta\boldsymbol{x}_j, 0)$ and $\boldsymbol{x}_t^- = \sum_{j=1}^t \Delta\boldsymbol{x}_j^- = \sum_{j=1}^t \min(\Delta\boldsymbol{x}_j, 0)$ are partial sum processes of positive and negative changes in $\boldsymbol{x}_t$. Following SYG, we assume a single known threshold value of zero to ensure that the model retains a clear economic interpretation.[4]

The NARDL(p, q)-in-levels model embedding (2.1) is written as follows:

$$y_t = \sum_{j=1}^{p} \phi_j y_{t-j} + \sum_{j=0}^{q} \left(\boldsymbol{\theta}_j^{+\prime}\boldsymbol{x}_{t-j}^+ + \boldsymbol{\theta}_j^{-\prime}\boldsymbol{x}_{t-j}^-\right) + \varepsilon_t, \tag{2.2}$$

where the ϕ_j's are autoregressive parameters, $\boldsymbol{\theta}_j^+$ and $\boldsymbol{\theta}_j^-$ contain the asymmetric distributed-lag parameters, and ε_t is an iid process with zero mean and constant variance, σ_ε^2. The associated error correction representation is:

[4]We find that decomposing the Brent spot price in this way results in an approximate 60:40 split of observations in favour of the positive regime so we need not worry about estimation issues resulting from large differences in the regime probabilities.

$$\Delta y_t = \rho y_{t-1} + \boldsymbol{\theta}^{+\prime}\boldsymbol{x}_{t-1}^{+} + \boldsymbol{\theta}^{-\prime}\boldsymbol{x}_{t-1}^{-} + \sum_{j=1}^{p-1}\gamma_j \Delta y_{t-j} + \sum_{j=0}^{q-1}\left(\boldsymbol{\varphi}_j^{+\prime}\Delta\boldsymbol{x}_{t-j}^{+} + \boldsymbol{\varphi}_j^{-\prime}\Delta\boldsymbol{x}_{t-j}^{-}\right) + \varepsilon_t \quad (2.3)$$

where $\rho = \sum_{j=1}^{p}\phi_j - 1$, $\gamma_j = -\sum_{i=j+1}^{p}\phi_i$ for $j = 1, ..., p-1$, $\boldsymbol{\theta}^{+} = \sum_{j=0}^{q}\boldsymbol{\theta}_j^{+}$, $\boldsymbol{\theta}^{-} = \sum_{j=0}^{q}\boldsymbol{\theta}_j^{-}$, $\boldsymbol{\varphi}_0^{+} = \boldsymbol{\theta}_0^{+}$, $\boldsymbol{\varphi}_j^{+} = -\sum_{i=j+1}^{q}\theta_j^{+}$ for $j = 1, ..., q-1$, $\boldsymbol{\varphi}_0^{-} = \boldsymbol{\theta}_0^{-}$, $\boldsymbol{\varphi}_j^{-} = -\sum_{i=j+1}^{q}\theta_j^{-}$ for $j = 1, ..., q-1$, and $\boldsymbol{\beta}^{+} = -\boldsymbol{\theta}^{+}/\rho$ and $\boldsymbol{\beta}^{-} = -\boldsymbol{\theta}^{-}/\rho$ are the asymmetric long-run parameters. By specifying a marginal DGP of the form, $\Delta\boldsymbol{x}_t = \sum_{j=1}^{q-1}\boldsymbol{\Lambda}_j\Delta\boldsymbol{x}_{t-j} + \boldsymbol{v}_t$, and expressing ε_t conditionally on $\boldsymbol{v}_t$ such that $\varepsilon_t = \boldsymbol{\omega}'\left(\Delta\boldsymbol{x}_t - \sum_{j=1}^{q-1}\boldsymbol{\Lambda}_j\Delta\boldsymbol{x}_{t-j}\right) + e_t$ where e_t is uncorrelated with $\boldsymbol{v}_t$ by construction, it is straightforward to derive the conditional nonlinear ECM as follows:[5]

$$\Delta y_t = \rho y_{t-1} + \boldsymbol{\theta}^{+\prime}\boldsymbol{x}_{t-1}^{+} + \boldsymbol{\theta}^{-\prime}\boldsymbol{x}_{t-1}^{-} + \sum_{j=1}^{p-1}\gamma_j \Delta y_{t-j} + \sum_{j=0}^{q-1}\left(\boldsymbol{\pi}_j^{+\prime}\Delta\boldsymbol{x}_{t-j}^{+} + \boldsymbol{\pi}_j^{-\prime}\Delta\boldsymbol{x}_{t-j}^{-}\right) + e_t \quad (2.4)$$

where $\boldsymbol{\pi}_0^{+} = \boldsymbol{\theta}_0^{+} + \boldsymbol{\omega}$, $\boldsymbol{\pi}_0^{-} = \boldsymbol{\theta}_0^{-} + \boldsymbol{\omega}$, $\boldsymbol{\pi}_j^{+} = \boldsymbol{\varphi}_j^{+} - \boldsymbol{\omega}'\boldsymbol{\Lambda}_j$ and $\boldsymbol{\pi}_j^{-} = \boldsymbol{\varphi}_j^{-} - \boldsymbol{\omega}'\boldsymbol{\Lambda}_j$ for $j = 1, ..., q-1$.

Either of two tests for the existence of a stable long-run levels relationship may be used. The t_{BDM}-statistic proposed by Banerjee *et al.* (1998) tests H_0: $\rho = 0$ against H_1: $\rho < 0$ while the F_{PSS}-statistic developed by Pesaran *et al.* (2001, PSS) tests the joint null H_0: $\rho = \boldsymbol{\theta}^{+} = \boldsymbol{\theta}^{-} = 0$. The bounds testing approach of PSS provides a means to achieve valid inference in the presence of both stationary and nonstationary variables, a feature which SYG note is highly desirable in the presence of partial sum decompositions which may exhibit complex interdependencies. At a practical level SYG suggest counting the regressors in $\boldsymbol{x}_t$ prior to decomposition when selecting the appropriate critical values from those tabulated in PSS to ensure conservatism.

The specification in (2.4) is the most general form, admitting both long- and short-run asymmetries. The null hypotheses of long-run symmetry $\left(\boldsymbol{\beta}^{+} = \boldsymbol{\beta}^{-}\right)$ can be evaluated using a standard Wald test. Short-run symmetry restrictions can take either of two forms: $\boldsymbol{\pi}_i^{+} = \boldsymbol{\pi}_i^{-}$ for all $i = 0, ..., q-1$ or $\sum_{i=0}^{q-1}\boldsymbol{\pi}_i^{+} = \sum_{i=0}^{q-1}\boldsymbol{\pi}_i^{-}$, both of which may be tested using standard Wald tests – we will focus on the less restrictive additive case. Furthermore, in

[5] (2.4) corrects perfectly for the potential weak endogeneity of nonstationary explanatory variables, a feature that may be important given that the UK economy has non-negligible oil extraction and refining activity.

keeping with much of the existing literature, we will also evaluate the symmetry of the impact multipliers (*i.e.* H_0: $\pi_0^+ = \pi_0^-$). Finally, SYG show that the asymmetric dynamic multiplier effects on y_t associated with unit changes in $\boldsymbol{x}_t^+$ and $\boldsymbol{x}_t^-$ can be computed recursively from the parameters of the NARDL-in-levels representation, (2.2).

3. Estimation Results

Our dataset comprises 171 monthly observations from January 1999 to March 2013 on the spot price of Brent crude oil (£/bbl) and the retail price of unleaded petrol, derv, kerosene and gas oil, both pre-tax and duty (hereafter PTD) and inclusive of tax and duty (ITD), measured in pence per litre.[6] The data are converted into indices (2000Y=100) and logged prior to estimation.

Figure 1(a) shows the relatively close comovement between the crude oil price and the four PTD product prices. A closer inspection of the data reveals that the rate inflation of the crude oil price over our sample period has been considerably higher on average and also more volatile than the inflation rates of the refined products, particularly when the latter are quoted on a PTD basis (see Table 1 for descriptive statistics of annual inflation rates for each variable). Interestingly, both the mean and standard deviation of PTD price inflation have been much lower for road fuels than non-road fuels while no such pattern is visible in the case of ITD price inflation. This is suggestive of PTD price-smoothing in the case of road fuels.

Figure 1(b) plots the proportion of the end-user price which is accounted for by VAT and duty, and reveals that road fuels are much more heavily taxed than non-road fuels.[7]

[6] The Brent spot price is converted from US$/bbl to £/bbl using the period average exchange rate – both series are downloaded from the IMF's International Financial Statistics. Our decision to convert the spot price into Sterling rather than to include both the dollar-denominated series and the bilateral exchange rate was informed by initial experimentation with the data in which the exchange rate was rarely found to be significant. This may reflect the UK's position as a major oil trader with considerable domestic reserves. The PTD and ITD price series are sourced from the UK Department of Energy and Climate Change via the Office for National Statistics.

[7] While road fuels are liable to VAT at the standard rate (currently 20%), domestic non-road fuels are subject to a reduced rate (currently 5%). Similarly, road fuels attract higher duty than non-road fuels in the UK.

The proportion of duty gradually increases reflecting the controversial *escalator* system that governed changes in fuel duty in the UK for much of our sample. This has introduced an autonomous upward drift into ITD prices unrelated to input costs which is likely to weaken the extent to which ITD prices track crude oil prices. Since most consumers will only observe ITD prices, this suggests that they may perceive that the linkage between crude oil prices and refined product prices is weaker than it in fact is. Furthermore, consumers may either fail to perceive asymmetric price adjustments by firms or they may perceive 'false' asymmetries related to changes in duty and unrelated to firms' pricing decisions. Public perceptions of the nature and equity of fuel price changes are likely to be of interest to policymakers given that fuel demand is highly inelastic and it accounts for a non-negligible proportion of the average British household's consumption basket. Moreover, the three significant fuel protests that have been staged since 2000 underscore that fuel pricing is a highly sensitive political issue.

– TABLE 1 & FIGURE 1 ABOUT HERE –

Table 2 summarises our key estimation results. We present results for eight NARDL models which capture the (asymmetric) transmission of crude oil price changes to both the PTD and ITD prices of each of the four refined petroluem products that we consider.[8] Figure 2 plots the associated cumulative dynamic multipliers. Focusing initially on the PTD results, we find that the speed of adjustment is somewhat sluggish at 29-37% per month, with slightly higher values associated with road fuels than non-road fuels. Sluggish adjustment is associated with relatively prolonged periods of mispricing and is often considered indicative of weak competition. We find no evidence of long-run asymmetry for road fuels but significant evidence that PTD non-road fuel prices react somewhat more strongly to negative

[8]General-to-specific lag selection was employed starting with $p_{max} = q_{max} = 5$ using a unidirectional 5% decision rule. As a robustness check, we also estimated the models using the two-step Engle-Granger (EG) framework with general-to-specific lag selection in the second step. The estimation results are qualitatively similar in both cases. The principal differences are as follows: (i) the EG framework provides no support for cointegration in the ITD case for either unleaded petrol or derv; (ii) the EG long-run coefficients are considerably smaller than the equivalent NARDL estimates; and (iii) the speed of error correction is substantially slower in the EG case than the NARDL case. Full estimation results are available on request.

than positive crude oil price changes in the long-run (this effect may relate to differences in market structure, as discussed below). In economic terms, the asymmetry is modest but it nevertheless cautions against the use of untested long-run linearity restrictions, especially as long-run mis-specifications can seriously jeopardise estimation of the ECM dynamics.

– TABLE 2 & FIGURE 2 ABOUT HERE –

We find a long-run coefficient of approximately 0.8 for both unleaded petrol and derv, indicating that consumers are somewhat insulated from fluctuations in the crude oil market in the long-run. This result is consistent with the estimates reported by BCG and also with the descriptive statistics reported in Table 1. Given our finding of long-run symmetry in these cases, there is no evidence of long-run rent-seeking behaviour. Interestingly, we find evidence of a considerably stronger long-run linkage between crude oil prices and the PTD prices of kerosene and gas oil. The distinction between the long-run pricing behaviour of road and non-road fuels may reflect differences in the structure of their respective markets. Non-road fuels are typically delivered in large average volumes directly to the customer at a relatively low frequency, subject to a medium-term contractual agreement. This setting may furnish the buyer with additional bargaining power and provides a greater reward to consumer search effort than in the case of road fuels, factors that will lead sellers to strongly pass on beneficial cost shocks. Similarly, the large average sales volume and low frequency of transactions will reduce the seller's incentive (and perhaps their ability) to absorb adverse cost shocks, indicating that these too will be passed on strongly.

We find significant evidence of additively asymmetric dynamic adjustment in all cases except unleaded petrol. Our results indicate that a crude oil price increase is passed through more forcefully than a price decrease in the periods immediately following the shock. The asymmetry arises on impact for derv but with a mild lag for the non-road fuels. These results determine the shape of the dynamic multipliers in the left column of Figure 2, where we observe a strong and rapid reaction to positive changes but a more gradual response to negative changes. The heavy dashed red line in each figure plots the difference between the effect of a one percent positive shock and a one percent negative shock to the crude oil spot price on the price of the refined product, while the light dashed lines provide two standard error intervals. This representation provides a stark illustration of the rockets and feathers effect in action in UK PTD fuel prices. A number of theoretical explanations for such asymmetry may be found in the literature, many of which invoke oligopolistic competition (BCG) or nonlinear search effort (Johnson, 2002).

At this stage it seems that our results have relatively unambiguous consumer welfare and antitrust implications but it remains to be seen if these are robust to the analysis of ITD prices. The results of NARDL estimation for the ITD case are reported in the right columns of Tables 2 and Figure 2. Three striking results emerge: (i.) ITD road fuel prices are much less responsive to the crude oil market than the ITD prices of non-road fuels; (ii.) ITD prices adjust much more slowly than PTD prices; and (iii.) ITD price adjustment is symmetric in all cases except kerosene, which has the smallest and least variable duty/VAT component.

The first two points can be attributed in large part to the escalator system which created an upward drift in ITD prices independent of the price of crude oil. As mentioned above, this may create the impression that energy prices are relatively unresponsive to the crude oil market among consumers that only observe ITD prices. However, it is the third point which is of particular interest, as it suggests that VAT and duty adjustments may have had considerable effects on energy pricing decisions, with the implication that British *consumers facing ITD prices are largely insulated from asymmetries* at the pump.[9] This effect may result in part from the use of discretionary changes in VAT and duty to offset negative oil supply shocks, for example. This finding complicates the welfare and antitrust implications arising from the analysis of PTD prices. Indeed, it raises the intriguing possibility that if firms engage in focal point pricing using the ITD price, then they may adjust PTD prices asymmetrically in order to achieve a desired path of ITD prices. This suggests that

[9]During our sample period, changes of at least 0.25ppl in the implied duty in our dataset occurred fourteen times for unleaded and derv, twice for kerosene and eight times for gas oil. Meanwhile, the standard rate of VAT was reduced from 17.5% to 15% from 2008m12–2009m12 inclusive (although this was offset for unleaded petrol and derv by a simultaneous 2ppl increase in duty), and subsequently increased to 20% in 2011m01.

oligopolistically competitive firms may have been able to exploit the tax system to conceal coordinated rent-seeking asymmetric PTD price adjustments behind symmetric adjustments of listed ITD prices. The industry is currently under intense scrutiny over the alleged manipulation of oil prices by BP and Shell so the possibility of antitrust issues at the retail level should be of immediate concern to regulators.

Our results raise a general concern about the design of tax policies aimed at curbing the consumption of price-inelastic goods. Escalator-type policies have been widely used in the UK, with the 'vice tax' on alcohol and tobacco being a current high profile example. However, our results indicate that such tax systems may distort the information content of listed ITD prices, thereby hampering the ability of consumers to extract signals about the pricing policies of distributors. Particularly in oligopolistic markets this provides considerable scope for collusion to the detriment of consumer welfare.

4. Concluding Remarks

Using the Nonlinear ARDL framework developed by SYG, we have found strong evidence of the rockets and feathers effect in action in three out of four major PTD fuel markets in the UK. As with Bacon's (1991) original study, this raises issues of rent-seeking under oligopolistic coordination. However, our results raise the further intriguing possibility that firms may have exploited UK tax legislation to conceal asymmetric pricing behaviour. The difference in the extent and pattern of pass-through into PTD and ITD prices suggests that existing studies that focus on just one of the two (usually PTD as opposed to ITD) may miss an important aspect of the nature of price adjustment in the retail energy industry. Our results also raise serious concerns over the design of escalator systems for the taxation of socially undesirable price-inelastic goods.

Acknowledgments

We are grateful to the Editor, Badi Baltagi, and to one anonymous referee. We have benefitted from the insightful discussion of Raphael Brun-Aguerre, David Byrne, Ana-Maria Fuertes, John Hunter, Minjoo Kim, Gordon Leslie, Camilla Mastromarco, Viet Nguyen, Kevin Reilly, Laura Serlenga, Ron Smith and Till van Treeck. Greenwood-Nimmo acknowledges the hospitality and financial support of the University of York during a sequence of visits in which much of the work in this paper was conducted.

Literature Cited

Asplund M, Eriksson R, Friberg R. 2000. Price adjustment by a gasoline retail chain. *Scandinavian Journal of Economics* **102**: 101-121.

Bachmeier LJ, Griffin JM. 2003. New evidence on asymmetric gasoline price responses. *The Review of Economics and Statistics* **85**: 772-776.

Bacon RW. 1991. Rockets and feathers: The asymmetric speed of adjustment of UK retail gasoline prices to cost changes. *Energy Economics* **13**: 211-218.

Balke NS, Brown SP, Yücel MK. 1998. Crude oil and gasoline prices: An asymmetric relationship? *Federal Reserve Bank of Dallas Economic and Financial Policy Review* Q1: 2-11.

Banerjee A, Dolado J, Galbraith JW, Hendry DF. 1993. Co-integration, error correction, and the econometric analysis of non-stationary data. Oxford University Press: Oxford.

Banerjee A, Dolado J, Mestre R. 1998. Error-correction mechanism tests for cointegration in a single-equation framework. *Journal of Time Series Analysis* **19**: 267-283.

Borenstein S, Cameron C, Gilbert R. 1997. Do gasoline prices respond asymmetrically to crude oil price changes? *The Quarterly Journal of Economics* **112**: 305-339.

Borenstein S, Shepard A. 2002. Sticky prices, inventories, and market power in wholesale gasoline markets. *Rand Journal of Economics* **33**: 116-139.

Galeotti M, Lanza A, Manera M. 2003. Rockets and feathers revisited: An international comparison on European gasoline markets. *Energy Economics* **25**: 175-190.

Granger CWJ, Yoon G. 2002. *Hidden cointegration.* Mimeo: University of California San Diego.

Grasso M, Manera M. 2007. Asymmetric error correction models for the oil-gasoline price relationship. *Energy Policy* **35**: 156-177.

Honarvar, A. 2009. Asymmetry in retail gasoline and crude oil price movements in the United States: An application of hidden cointegration technique. *Energy Economics* **31**: 395-402.

Johnson RN. 2002. Search costs, lags and prices at the pump. *Review of Industrial Organization* **20**: 33-50.

Pesaran MH, Shin Y. 1998. An autoregressive distributed lag modelling approach to cointegration analysis. In *Econometrics and Economic Theory: The Ragnar Frisch Centennial Symposium*, Strom S (ed.). Cambridge University Press: Cambridge.

Pesaran MH, Shin Y, Smith RJ. 2001. Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics* **16**: 289-326.

Radchenko S. 2005. Oil price volatility and the asymmetric response of gasoline prices to oil price increases and decreases. *Energy Economics* **27**: 708-730.

Reilly B, Witt R. 1998. Petrol price asymmetries revisited. *Energy Economics* **20**: 297-308.

Shin Y, Yu B. and Greenwood-Nimmo, M.J. 2013. Modelling Asymmetric Cointegration and Dynamic Multipliers in a Nonlinear ARDL Framework. In *Festschrift in Honor of Peter Schmidt*, William C. Horrace and Robin C. Sickles (Eds.). Springer Science & Business Media: New York.

	p_o	p^{PTD}_{unld}	p^{PTD}_{derv}	p^{PTD}_{krsn}	p^{PTD}_{gasl}	p^{ITD}_{unld}	p^{ITD}_{derv}	p^{ITD}_{krsn}	p^{ITD}_{gasl}
Mean	61.71	9.80	10.64	39.76	29.20	38.75	50.14	39.76	38.29
Std. Dev.	35.62	10.01	10.33	28.69	26.45	26.84	27.35	28.66	32.56
Skewness	0.89	0.00	0.13	0.17	0.02	0.42	0.88	0.17	0.12
Kurtosis	2.02	-0.48	0.31	-0.31	-0.38	0.31	1.72	-0.30	-0.48

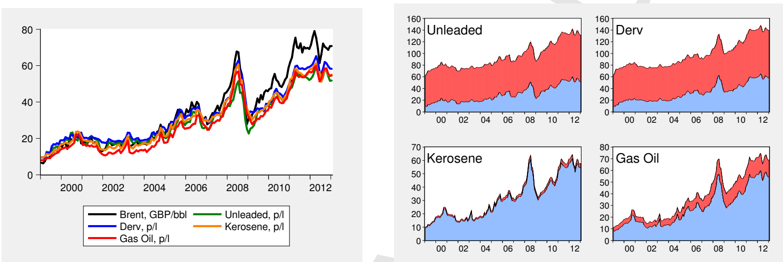
NOTES: p_o denotes the Brent crude oil price converted from US$/bbl to £/bbl. In all cases, the reported statistics are computed using the indexed representation of the data (2000Y=100) before it is logged for estimation.

Table 1: Descriptive Statistics – Annual Rate of Inflation of Each Variable

	p_{unld}^{PTD}	p_{derv}^{PTD}	p_{krsn}^{PTD}	p_{gasl}^{PTD}	p_{unld}^{ITD}	p_{derv}^{ITD}	p_{krsn}^{ITD}	p_{gasl}^{ITD}
Estimated Coefficients								
ρ	-0.36 ***	-0.37 ***	-0.33 ***	-0.29 ***	-0.06 **	-0.08 ***	-0.31 ***	-0.15 ***
β^+	0.78 ***	0.82 ***	1.00 ***	1.24 ***	0.32 ***	0.44 ***	1.01 ***	1.12 ***
β^-	0.78 ***	0.83 ***	1.05 ***	1.33 ***	0.32 *	0.45 ***	1.06 ***	1.18 ***
π_0^+	0.39 ***	0.42 ***	0.47 ***	0.67 ***	0.11 ***	0.11 ***	0.47 ***	0.53 ***
π_0^-	0.35 ***	0.17 ***	0.45 ***	0.51 ***	0.14 ***	0.11 ***	0.48 ***	0.41 ***
$\sum_{j=1}^{q-1} \pi_j^+$	0.76 ***	0.56 ***	0.75 ***	0.90 ***	0.37 ***	0.23 ***	0.75 ***	0.71 ***
$\sum_{j=1}^{q-1} \pi_j^-$	0.66 ***	0.17 ***	0.45 ***	0.34 ***	0.38 ***	0.27 ***	0.48 ***	0.68 ***
Symmetry Tests								
H_0: $\beta^+ = \beta^-$	0.05	1.28	6.71 ***	17.61 ***	1.11	0.07	6.89 ***	2.01
H_0: $\pi_0^+ = \pi_0^-$	0.14	5.60 **	0.03	1.55	0.30	0.00	0.00	1.21
H_0: $\sum_{j=1}^{q-1} \pi_j^+ = \sum_{j=1}^{q-1} \pi_j^-$	0.31	7.65 ***	4.07 **	10.75 ***	0.03	0.32	3.74 *	0.04
Diagnostics								
F_{PSS}	13.82 ***	25.88 ***	18.58 ***	22.56 ***	3.04	6.06 **	17.48 ***	6.64 **
t_{BDM}	-6.37 ***	-8.50 ***	-7.07 ***	-7.37 ***	-2.41	-3.72 **	-6.82 ***	-3.91 ***
BG Test (NR^2)	15.96	15.47	8.76	4.40	14.19	7.07	8.99	7.39
$\bar{R}^2$	0.70	0.64	0.65	0.67	0.65	0.59	0.66	0.66

NOTES: The notation for the estimated coefficients relates to Equation (2.4). The three reported symmetry tests are standard Wald tests. The BG test is the Breusch-Godfrey serial correlation test.*** denotes significance at the 1% level, ** the 5% level and * the 10% level. The relevant $k = 1$ critical values reported by PSS for the t_{BDM} statistic are -2.91 -3.22 -3.82 at the 10%, 5% and 1% levels. The equivalent critical values for the F_{PSS} statistic are 4.78, 5.73 and 7.84.

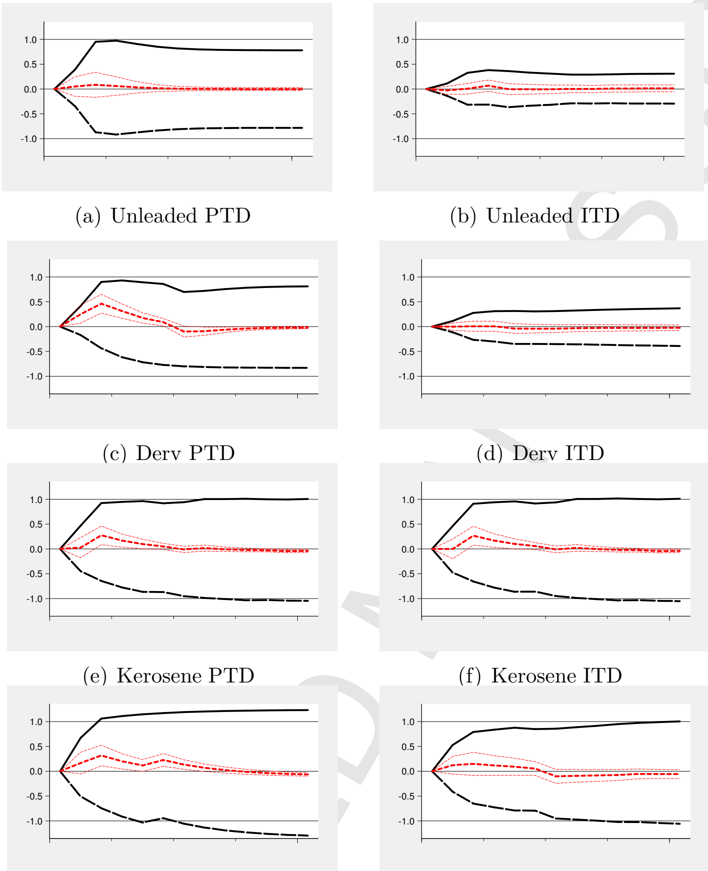
Table 2: NARDL Estimation Results



(a) Crude Oil Spot Price (GBP/bbl) and PTD Product Prices (p/l)

(b) VAT and Duty by Product, p/l (blue: PTD price; red: VAT & duty)

Figure 1: The Proportion of VAT and Duty by Product



(a) Unleaded PTD (b) Unleaded ITD

(c) Derv PTD (d) Derv ITD

(e) Kerosene PTD (f) Kerosene ITD

(g) Gas Oil PTD (h) Gas Oil ITD

Figure 2: Cumulative Dynamic Multipliers. The solid (dashed) black line is the cumulative dynamic multiplier with respect to a 1% positive (negative) change in the oil price while th heavy dashed red line plots the difference between the two. The light dashed red lines report the two standard error confidence interval for the difference line computed by stochastic simulation. Tick marks on the horizontal axis represent 3 month intervals while the vertical axis is in percentage points.