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Asymmetric Price Responses and the Underlying Energy Demand Trend: Are they Substitutes or Complements? Evidence from Modelling OECD Aggregate Energy Demand

Olutomi I Adeyemi, David C Broadstock, Mona Chitnis,
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October 2008

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ABSTRACT

A number of energy demand studies have considered the importance of modelling Asymmetric Price Responses (APR), for example, the often-cited work of Gately and Huntington (2002). Griffin and Schulman (2005) questioned the asymmetric approach arguing that this is only capturing energy saving technical progress. Huntington (2006), however, showed that for whole economy aggregate energy and oil demand there is a role statistically for both APR and exogenous energy saving technical change. In a separate strand of the literature the idea of the Underlying Energy Demand Trend (UEDT) has been developed, see for example Hunt et al. (2003a and 2003b) and Dimitropoulos et al. (2005). They argue that it is important, in time series energy demand models, to allow for stochastic trends (or UEDTs) based upon the structural time series/dynamic regression methodology recommended by Harvey (1989, 1997).

This paper attempts to bring these strands of the literature together by conducting tests for the UEDT and APR in energy demand models within both a panel context (consistent with the Huntington, 2006 approach) and the structural time series modelling framework. A set of tests across a range of specifications using time-series and panel data are therefore undertaken in order to ascertain whether energy saving technical change (or the more general UEDT) and APR are substitutes for each other when modelling energy demand or whether they are actually picking up different influences and are therefore complements.

Using annual whole economy data for 17 OECD countries over the period 1960 – 2004 the results suggest that in general the UEDT and ARP are complementary estimation methodologies when modelling aggregate energy demand. It is argued therefore that energy demand modellers should not assume at the outset that one method is superior to the other. Moreover, wherever possible, a general model (be it in a time series or panel context) that includes a 'non linear UEDT' and APR should be initially estimated, and only if accepted by the data should symmetry and/or a more restrictive UEDT be imposed.

JEL Classification: C22, C23, C52, Q41.

Key Words: Energy Demand, OECD, Asymmetric Price Responses, Underlying Energy Demand Trend.

Asymmetric Price Responses and the Underlying Energy Demand Trend: Are they Substitutes or Complements? Evidence from Modelling OECD Aggregate Energy Demand[*]

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1.   Introduction

Energy demand models are often developed on the premise (or more appropriately on the assumption) that consumer behaviour is defined by symmetric responses to rising or falling prices and income, recent examples being Ahmadian et al. (2007) and Lescaroux and Rech (2008). It is equally plausible, however, that consumers might react differently to price rises than they would to price falls, be it because of habit formation, the desire to improve life quality or any other reason. Consequently, asymmetric price decompositions have found increasing use in the energy demand literature, see for example, Dargay (1992), Dargay and Gately (1995a, 1995b and 1997), Gately (1993), Gately and Huntington (2002), Griffin and Schulman (2005), Ryan and Plourde (2002) and Adeyemi and Hunt (2007). [1]

An influential and often quoted paper by Gately and Huntington (2002) eloquently demonstrates why, and how, consumers of energy will respond differently to, not only price

[1] Although it should be noted, this is not an exhaustive list, with a number of other papers also addressing the issue of asymmetry when modelling energy demand.

cuts and price rises, but also to price rises above the previous maximum and price recoveries below the previous maximum.[2] Furthermore, using panel data and a Koyck lag model they provide empirical estimates for OECD and Non-OECD energy and oil demand, showing that asymmetric price responses, achieved by decomposing the price variable, are very often accepted by the data.

Griffin and Schulman (2005), however, argue that the price asymmetry methodology adopted by Gately and Huntington (2002) is really only acting as a proxy for energy-saving technical change. They therefore included time dummies as a proxy for technical progress both in symmetric and asymmetric price response models for OECD energy (and oil) demand, concluding that they "prefer a simple symmetric price specification that separately accounts for technical change via time dummies in a panel data model" (p. 19). In his response, Huntington (2006) formally tests the restrictions of symmetry and no time dummies in the Griffin and Schulman (2005) models and finds that statistically the restrictions are not accepted by the data, arguably displaying that in explaining past OECD energy (and oil) demand both asymmetric price responses and the exogenous time dummies might have a role to play. Adeyemi and Hunt (2007) further explored these ideas for OECD Industrial Energy Demand also using a Koyck lag model in a panel context. They also found that from a statistical perspective asymmetric price responses and the exogenous time dummies both have a role to play, but given individual coefficient values and level of significance led them to conclude that the asymmetric model without time dummies is to be preferred for "pragmatic reasons" (p. 706). Nevertheless Adeyemi and Hunt (2007) conclude that their

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[2] In fact, Gately and Huntington (2002) also demonstrate that this might also apply to changes in economic activity; however, overall symmetry for the income responses is generally favoured over asymmetry. This is ignored in this paper since the discussion focuses on asymmetric price responses and underlying exogenous energy saving trends, although the Huntington (2006) asymmetry tests within a panel context and the further tests utilised in this paper in a time series context could equally be applied to testing for the asymmetry of an economic activity variable.

"exercise shows that when estimating energy demand models and considering the important issue of energy-saving technical progress (and other exogenous trends) a general flexible approach should initially be adopted" and that the "chosen model should be the one that is accepted by the data while the same time conforming to economic theory - but this should be estimated and tested rather than imposed at the outset" (p. 706).

The above illustrates the debate in the energy demand literature concerning asymmetry, in particular in a panel context, and in their conclusion Griffin and Schulman (2005) state that in future research it is "imperative that we understand the extent to which technical change is neutral or price-induced" (p. 19). This paper therefore explores this issue further by trying to formally test, when modelling energy demand, whether a specification with Asymmetric Price Responses (APR) can be regarded as a substitute or complement for 'exogenous energy saving technical change via time dummies'.

The above is very 'panel data specific'. An attempt is made here therefore to link this to, and develop analogous tests for, a separate strand of the energy demand modelling literature; that is the most appropriate way to account for technical progress when modelling energy demand using time series data. For a long while, the most common way to try to capture the technical progress of the appliance and capital stock was by the inclusion of a simple deterministic time trend. Although there were arguments against this (see Kouris 1983a and 1983b for example) it was seen by many (see Beenstock and Willcocks 1981 and 1983 for example) as the best procedure available given the lack of any feasible alternative.[3]

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[3] This debate is considered in full in Hunt et al. (2003a and 2003b).

More recently Hunt et al. (2003a, 2003b), Hunt and Ninomiya (2003) and Dimitropoulos et al. (2005) have argued that, given the advances in Structural Time Series Modelling (STSM), see Harvey (1989, 1997), a stochastic trend, entitled the Underlying Energy Demand Trend (UEDT), should be incorporated in any initial general time series model of energy demand. Moreover, the UEDT captures not only exogenous technical progress (or energy saving technical change) but other important socio-economic effects (see Hunt and Ninomiya, 2003).[4]

One potential problem with this approach however, is that arguably the estimated UEDTs may just be a proxy for APR, so what is essentially a price induced asymmetric response is captured as an exogenous effect given that the specification only allows for symmetric price responses. This is therefore seen as similar to the issue raised by Griffin and Schulman (2005) who conversely argued that, in a panel context, APR just proxy energy saving technical progress whereas for a time series model the stochastic UEDT could arguably proxy APR. Furthermore, the estimated coefficients for the time dummies in a panel model are likely to have a 'non-linear' shape with periods where they increase as well as decrease (see the example from Griffin and Schulman, 2005 in Figure 1a) – similar to the non-linear estimated UEDTs in a time series model (see the example from Dimitropoulos et al. 2005 in Figure 1b).

In summary, there is a need to try to determine whether APR (in both panel and time series models) or the UEDT (estimated via time dummies in panel models or a stochastic trend in time series models) is ***preferred*** to each other or do ***both*** schools of thought have a role to play. In other words, as stated above, are they substitutes or complements when modelling energy demand?

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[4] Discussion on the STSM method to derive the UEDT is given in the methodology section.
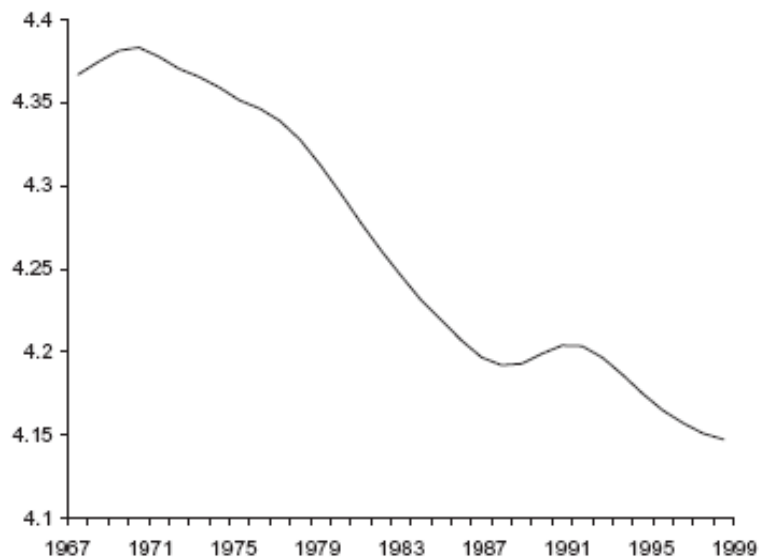
Figure 1

a) Example of the UEDT from Griffin and Schulman (2005, p. 18) based on panel data estimation with time dummies.
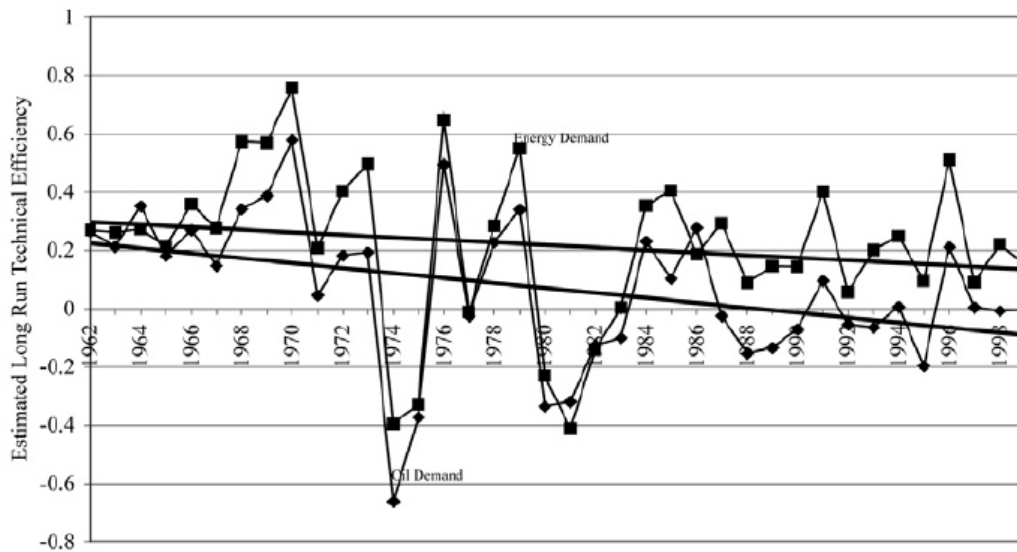
OECD Oil and Energy Demand Trends

b) Example of the UEDT from Dimitropoulos et al. (2005, p. 243) based on time series estimation with a stochastic trend.

UK Whole Economy Aggregate Energy Demand Trend

The remainder of the paper sets up a formal testing procedure to try to answer this question for aggregate energy demand using a sample of 17 OECD countries over the period 1960 to 2004. The next section discusses the philosophy and methodology of the testing procedure.

Section 4 provides a brief overview of the data and presents the results. A summary and conclusion is given in Section 5.

2. Testing philosophy and methodology

The testing philosophy utilised here is underpinned by the 'general-to-specific' modelling school of thought in that general unrestricted models are initially hypothesised with restrictions of symmetry or no UEDT imposed and tested both in a time series and panel data context. The tests may be thought of as *either* testing whether there is a role to play for a UEDT in a model that incorporates asymmetric price responses (denoted *Test 1* below) *or* testing whether there is a role to play for APR in a model that incorporates a UEDT (denoted *Test 2* below).[5] In other words, the intention is to provide a testing framework that helps clarify whether the UEDT and APR are substitutes or complements. To do this it is assumed that the UEDT is modelled using time dummies in a panel data context (as advocated by Griffin and Schulman, 2005) or by a stochastic trend in a time series context (as advocated in Hunt et al. 2003a and 2003b). Moreover, APR are modelled in both a panel context and a time series context using the decomposition of the price variable explained below (as advocated in Gately and Huntington, 2002, for example).

Given the 'general to specific' framework, a number of different models are tested. For the time series data it includes a 'static' model, a 'partial adjustment model' (or 'PAM') and an 'Autoregressive Distributed Lag Model with a lag of one year' (or 'ARDL'[6]) given an ARDL

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[5] Note that it is assumed from the outset that there is a role to play for at least one of these in the general model. That is, tests for whether there is a role for *either* a model of asymmetric price responses *or* a UEDT in a model with asymmetric model with no UEDT are not reported here; given the emphasis in the literature.

[6] Technically this is ARDL(1,1) given there is a one year lag on the autoregressive and distributed lag components but ARDL is used for short hereafter.

model is used by Hunt et al. (2003b), Hunt and Ninomiya (2003) and Dimitropoulos et al. (2005). For the panel data, this includes a 'static' model, a 'PAM' and a 'Koyck' lag model given its popularity, following Gately and Huntington (2002). These specifications are chosen because they have been used in a number of previous papers, but more importantly to ensure that the results of the tests are not 'specification dependent'. Table 1 therefore details *Test 1* and *Test 2* in a time series context and Table 2 details *Test 1* and *Test 2* in a panel data context (based upon the tests in Huntington, 2006).

Time Series Data Tests

The time series tests are undertaken using Harvey's (1989) STSM, which allows for the estimation of a stochastic trend. Equations (1a), (1b), and (1c) in Table 1 represent the unrestricted models for the three different specifications ('static', 'PAM' and 'ARDL') for *Test 1*, where e_t is the natural logarithm of energy consumption per capita (E_t) and y_t is the natural logarithm of GDP per capita (Y_t) for each country. p_t^m, p_t^r and p_t^c represent the decomposition of p_t, the natural logarithm of the real price of energy (P_t) defined, following Gately and Huntington (2002), as the 'cumulative increase in the log of the maximum historical real energy price', 'cumulative sub maximum increase in log of the real energy price', and the 'cumulative decrease in log of real energy price', respectively.[7]

ε_t is a random white noise disturbance term, $\varepsilon_t \sim NID(0, \sigma_\varepsilon^2)$ and μ_t, is the stochastic trend which in its general form is assumed to have the following stochastic process:

$$\mu_t = \mu_{t-1} + \alpha_{t-1} + \eta_t \qquad\qquad \eta_t \sim NID(0, \sigma_\eta^2) \qquad\qquad \textbf{(4a)}$$

$$\alpha_t = \alpha_{t-1} + \xi_t \qquad\qquad\qquad \xi_t \sim NID(0, \sigma_\xi^2) \qquad\qquad \textbf{(4b)}$$

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[7] See Gately and Huntington (2002) for more details.

The trend includes a level component, equation (4a), and a slope component, equation (4b), with its nature dependent upon the variances σ_η^2 and σ_ξ^2, known as hyperparameters so that it can be either linear or non-linear depending on whether the hyperparameters are zero or not. However, in order to ensure that the analysis is tractable and aid exposition of the testing procedure the slope component of the trend is omitted here so the simpler representation is given by:

$$\mu_t = \mu_{t-1} + \eta_t \qquad\qquad \eta_t \sim NID(0, \sigma_\eta^2) \qquad\qquad\qquad \textbf{(5)}$$

so that the stochastic trend is specified when the hyperparameter $\sigma_\eta^2 \neq 0$.[8] The unrestricted models for the three specifications are therefore represented by equations (1a) and (5), equations (1b) and (5), and equations (1c) and (5) respectively.[9]

As illustrated in Table 1, *Test 1* (a likelihood ratio test) imposes the null hypothesis restriction that the variance of the trend term is equal to zero so that $\mu_t=\mu_{t-1}=\mu$, which is constant and hence there is no trend, given by equations (2a), (2b) and (2c) for the three specifications respectively. This test therefore maintains APR and tests to see whether there is a role for the stochastic UEDT. If the null is accepted, it suggests that there is no role and hence asymmetry 'dominates' the UEDT; whereas if the null is rejected there is a role for the UEDT suggesting that APR and the UEDT are complements.

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[8] I.e. it is assumed that: $\sigma_\xi^2 = \alpha = 0$.

It is worth noting therefore, that this allows for less 'variation' in the source of the stochastic trend than the more general specification given by equations (4a) and (4b) so the tests are arguably slightly biased *against* the acceptance of a stochastic trend.

[9] The STSM is estimated via maximum likelihood in conjunction with a Kalman filter using the software STAMP 6.3 (Koopman et al. 2000).

Table 1: Tests in a time-series context

Unrestricted models

Static	PAM	ARDL
$e_t = \mu_t + \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \varepsilon_t \qquad \text{(1a)}$	$e_t = \mu_t + \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \beta^{e1} e_{t-1} + \varepsilon_t \qquad \text{(1b)}$	$e_t = \mu_t + \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \beta^{y1} y_{t-1} + \beta^{m1} p_{t-1}^m + \beta^{r1} p_{t-1}^r + \beta^{c1} p_{t-1}^c + \beta^{e1} e_{t-1} + \varepsilon_t \qquad \text{(1c)}$

Test 1: $H_0 : \sigma_\eta^2 = 0$

Restricted models

Static	PAM	ARDL
$e_t = \mu + \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \varepsilon_t \qquad \text{(2a)}$	$e_t = \mu + \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \beta^{e1} e_{t-1} + \varepsilon_t \qquad \text{(2b)}$	$e_t = \mu + \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \beta^{y1} y_{t-1} + \beta^{m1} p_{t-1}^m + \beta^{r1} p_{t-1}^r + \beta^{c1} p_{t-1}^c + \beta^{e1} e_{t-1} + \varepsilon_t \qquad \text{(2c)}$

Test 2: $H_0 : \beta^m = \beta^r = \beta^c = \beta^p$

Restricted models

Static	PAM	ARDL
$e_t = \mu_t + \beta^y y_t + \beta^p p_t + \varepsilon_t \qquad \text{(3a)}$	$e_t = \mu_t + \beta^y y_t + \beta^p p_t + \beta^{e1} e_{t-1} + \varepsilon_t \qquad \text{(3b)}$	$e_t = \mu_t + \beta^y y_t + \beta^p p_t + \beta^{y1} y_{t-1} + \beta^{p1} p_{t-1} + \beta^{e1} e_{t-1} + \varepsilon_t \qquad \text{(3c)}$

As also shown in Table 1, *Test 2* (an F-test) imposes the null hypothesis restriction that the coefficients on the decomposed price terms are equal so that there is no APR.[10] *Test 2* therefore maintains the UEDT and tests to see whether there is a role for APR given by equations (3a), (3b) and (3c) with equation (5). If the null is accepted, then there is no role and hence the UEDT 'dominates' ARP, whereas if the null is rejected there is a role for APR suggesting that the UEDT and asymmetry are complements.

Panel Data Tests

The panel data tests are estimated using least squares estimation (either linear or non-linear depending on the specification).[11] Equations (6a), (6b), and (6c) in Table 2 represent the unrestricted models for the three different specifications ('static', 'PAM' and 'Koyck'[12]), where the variable definitions are those given above, but now in a panel data context: e_{it}, y_{it}, p_{it}, p_{it}^m, p_{it}^r and p_{it}^c. Like the time series counterparts these include asymmetric price responses but now allow for country fixed effects via the dummy variables, D_i and ε_{it} is a

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[10] The time series *Test 2* is implemented by first estimating the appropriate specification of equation (1) with equation (5) in STAMP and extracting the estimated stochastic trend $\hat{\mu}_t$ which is then imposed on the model and re-estimated in PcGive 10 (Doornik and Hendry, 2001) to re-generate the unrestricted model as follows:

Static Model: $e_t - \hat{\mu}_t = \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \varepsilon_t$

PAM: $\quad\quad e_t - \hat{\mu}_t = \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \beta^{e1} e_{t-1} + \varepsilon_t$

ARDL(1): $\quad e_t - \hat{\mu}_t = \beta^y y_t + \beta^m p_t^m + \beta^r p_t^r + \beta^c p_t^c + \beta^{y1} y_{t-1} + \beta^{m1} p_{t-1}^m + \beta^{r1} p_{t-1}^r + \beta^{c1} p_{t-1}^c + \beta^{e1} e_{t-1} + \varepsilon_t$

The restriction of symmetry $\beta^m = \beta^r = \beta^c = \beta^p$ for the static model and the PAM plus $\beta^{m1} = \beta^{r1} = \beta^{c1} = \beta^{p1}$ for the ARDL model is then imposed to give the restricted specification as follows:

Static Model: $e_t - \hat{\mu}_t = \beta^y y_t + \beta^p p_t + \varepsilon_t$

PAM: $\quad\quad e_t - \hat{\mu}_t = \beta^y y_t + \beta^p p_t + \beta^{e1} e_{t-1} + \varepsilon_t$

ARDL(1): $\quad e_t - \hat{\mu}_t = \beta^y y_t + \beta^p p_t + \beta^{y1} y_{t-1} + \beta^{p1} p_{t-1} + \beta^{e1} e_{t-1} + \varepsilon_t$

This is also estimated in PcGive and the standard F-test of linear restrictions calculated accordingly.

[11] Estimated in EViews 5.0 (2003)

[12] Details of the derivation of this model may be found in Gately and Huntington (2002) or Adeyemi and Hunt (2007).

random white noise disturbance term; $\varepsilon_{it} \sim NID(0, \sigma_{\varepsilon}^2)$. The UEDT is represented by the time dummies, D_t, following the arguments of Griffin and Schulman (2005) about energy saving technical change.

Test 1 in a panel context is the F-test of linear restrictions advocated by Huntington (2006). As shown in Table 2, this imposes the null hypothesis restriction that the coefficients on the time dummies are equal to zero, thus there is no fixed time effect, given by equations (7a), (7b) and (7c). Thus, analogous to the *Test 1* in a time series context, this test maintains APR and tests to see whether there is a role for the UEDT represented by the time dummies. If the null is accepted, it suggests that there is no role and hence APR 'dominate' the UEDT; whereas if the null is rejected there is a role for the UEDT suggesting that APR and the UEDT are complements.

Test 2 in a panel data context, also advocated by Huntington (2006), is again an F-test of linear restrictions. As also shown in Table 2, this imposes the null hypothesis restriction that the coefficients on the decomposed price terms are equal; hence, there are no APR given by equations (8a), (8b) and (8c). *Test 2* therefore maintains the UEDT represented by the time dummies, and tests to see whether there is a role for an APR. If the null is accepted, then there is no role and hence the UEDT 'dominates' asymmetry; whereas if the null is rejected there is a role for APR, suggesting that the UEDT and asymmetry are complements.

With the general testing procedure now in place, the following section presents and discusses the results from implementing the tests.[13]

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[13] It should be noted, that the intention here is to develop a general testing procedure to attempt to determine the roles of an APR and an UEDT; estimates of the actual functions will be part of further research.

Table 2: Tests in a panel data context

Unrestricted models

Static	PAM	Koyck
$e_{ti} = \beta + \beta^y y_{it} + \beta^m p_{it}^m + \beta^r p_{it}^r + \beta^c p_{it}^c$ $+ \delta_i D_i + \theta_t D_t + \varepsilon_{it}$ (6a)	$e_{ti} = \beta + \beta^y y_{it} + \beta^m p_{it}^m + \beta^r p_{it}^r + \beta^c p_{it}^c$ $+ \beta^{e1} e_{it-1} + \delta_i D_i + \theta_t D_t + \varepsilon_{ti}$ (6b)	$e_{it} = \beta + \beta^y (y_{it} - \beta^{e1} y_{it-1}) + \beta^m p_{it}^m$ $+ \beta^r p_{it}^r + \beta^c p_{it}^c + \beta^{e1} e_{it-1}$ $+ \delta_i D_i + \theta_t D_t + \varepsilon_{ti}$ (6c)

Test 1: $H_0 : \theta_t = 0$

Restricted models

Static	PAM	Koyck
$e_{ti} = \beta + \beta^y y_{it} + \beta^m p_{it}^m + \beta^r p_{it}^r + \beta^c p_{it}^c$ $+ \delta_i D_i + + \varepsilon_{it}$ (7a)	$e_{ti} = \beta + \beta^y y_{it} + \beta^m p_{it}^m + \beta^r p_{it}^r + \beta^c p_{it}^c$ $+ \beta^{e1} e_{it-1} + \delta_i D_i + \varepsilon_{ti}$ (7b)	$e_{it} = \beta + \beta^y (y_{it} - \beta^{e1} y_{it-1}) + \beta^m p_{it}^m$ $+ \beta^r p_{it}^r + \beta^c p_{it}^c + \beta^{e1} e_{it-1}$ $+ \delta_i D_i + \varepsilon_{ti}$ (7c)

Test 2: $H_0 : \beta^m = \beta^r = \beta^c = \beta^p$

Restricted models

Static	PAM	Koyck
$e_{ti} = \beta + \beta^y y_{it} + \beta^p p_{it} + \delta_i D_i$ $+ \theta_t D_t + \varepsilon_{it}$ (8a)	$e_{ti} = \beta + \beta^y y_{it} + \beta^p p_{it} + \beta^{e1} e_{it-1}$ $+ \delta_i D_i + \theta_t D_t + \varepsilon_{it}$ (8b)	$e_{it} = \beta + \beta^y (y_{it} - \beta^{e1} y_{it-1}) + \beta^p p_{it}$ $+ \beta^{e1} e_{it-1} + \delta_i D_i$ $+ \theta_t D_t + \varepsilon_{ti}$ (8c)

3. Data and Results

The annual data set covers the period 1960-2004 for 17 OECD countries: Austria, Belgium, Canada, Denmark, France, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK, and the US.[14] The primary source of these data is the International Energy Agency (IEA) database Energy Statistics of OECD Countries available at www.iea.org. This includes each country's aggregate energy consumption in thousand tonnes of oil equivalent (ktoe) and economic activity defined as GDP in billion 2000 US$ using PPPs over the whole period 1960-2004, both converted to per capita terms, denoted as E and Y respectively.

The index of real energy prices (2000=100) is also taken from the IEA database, but is only for the period 1978 – 2004. Consequently this is spliced with an aggregate real price index for each country derived from data in Baade (1981); calculated by weighting gas in households and industry, coal in households and industry, electricity in households and industry, gasoline, diesel fuel and kerosene by their fuel consumption shares. This produces a real aggregate energy price index for each country in 1972 prices (1972 = 100) over the period 1960 to 1980. The two series (1960 – 1980; 1972=100) and (1978 – 2004; 2000=100) are subsequently spliced using the ratio from the overlap year 1978 to obtain the real energy price index, denoted by P, for each country over the whole period 1960 to 2004 at 2000 prices (2000=100). The natural logarithm of the real energy price, p, being decomposed into p^m, p^r and p^c as discussed above.

The results of the estimation procedure are summarised in Table 3. This presents the probability values (or p-values) for *Test 1* and *Test 2* applied to the three specifications for

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[14] Further discussion of the data may be found in Al-Rabbaie and Hunt (2006) where a similar data set is used.

time series estimates for each country individually and the 17 countries as a panel. In addition, based on a 5% significance level, the final three columns indicate whether the null hypothesis is rejected or accepted by ticks and crosses.

- A cross (X) denotes that the null hypothesis is rejected indicating that:
    - *either* adding the UEDT to an asymmetric specification improves the model (*Test 1*);
    - *or* adding APR to a symmetric model with a UEDT improves the model (*Test 2*).
- A tick (√) denotes that the null hypothesis is unable to be rejected indicating that:
    - *either* adding a UEDT to an asymmetric specification does not improve the model (*Test 1*);
    - *or* adding APR to a symmetric model with a UEDT does not improve the model (*Test 2*).

Starting with the time series results, for eight out of the 17 countries (Canada, Denmark, Greece, Ireland, Japan, Norway, Portugal and the UK) the null hypothesis is rejected for both *Test 1* and *Test 2* for all three specifications, clearly suggesting that for these countries, the UEDT and APR are complements. For five out of the 17 countries (Austria, France, Netherlands, Switzerland and USA) the null hypothesis is always rejected for *Test 2* whereas for *Test 1* the null hypothesis is unable to be rejected for one out of the three specifications considered. This suggests that generally the UEDT and APR complement each other, although this may not always be the case with asymmetric price response potentially dominating the UEDT for these five countries when there are lags in the model. Nevertheless, overall the results would still appear to suggest that APR and UEDT are complements for each other when modelling aggregate energy demand for each country.

Table 3: Test Results

Time series results			Static	PAM	ARDL	Static	PAM	ARDL
Austria		Test 1	0.000	0.010	0.193	X	X	√
		Test 2	0.000	0.000	0.000	X	X	X
Belgium		Test 1	0.653	0.999	0.368	√	√	√
		Test 2	0.000	0.000	0.000	X	X	X
Canada		Test 1	0.000	0.002	0.002	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
Denmark		Test 1	0.000	0.000	0.024	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
France		Test 1	0.000	0.090	0.038	X	√	X
		Test 2	0.000	0.000	0.000	X	X	X
Greece		Test 1	0.000	0.013	0.008	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
Ireland		Test 1	0.000	0.049	0.005	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
Italy		Test 1	0.000	0.171	0.745	X	√	√
		Test 2	0.000	0.000	0.000	X	X	X
Japan		Test 1	0.000	0.014	0.002	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
Netherlands		Test 1	0.000	0.005	0.156	X	X	√
		Test 2	0.000	0.000	0.000	X	X	X
Norway		Test 1	0.000	0.004	0.006	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
Portugal		Test 1	0.000	0.000	0.000	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
Spain		Test 1	0.000	0.225	0.092	X	√	√
		Test 2	0.000	0.002	0.002	X	X	X
Sweden		Test 1	0.000	0.153	0.083	X	√	√
		Test 2	0.000	0.000	0.000	X	X	X
Switzerland		Test 1	0.000	0.017	0.810	X	X	√
		Test 2	0.000	0.000	0.023	X	X	X
UK		Test 1	0.000	0.000	0.002	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X
USA		Test 1	0.000	0.003	0.069	X	X	√
		Test 2	0.000	0.000	0.000	X	X	X
Panel Results			Static	PAM	Koyck	Static	PAM	Koyck
		Test 1	0.000	0.000	0.000	X	X	X
		Test 2	0.000	0.000	0.000	X	X	X

Note: Numbers refer to the p-values for the tests outlined in the text

X shows that the null hypothesis is rejected at the 5% level of significance

√ shows that the null hypothesis cannot be rejected at the 5% level of significance

For the remaining four countries, the null hypothesis is again always rejected for *Test 2* suggesting that APR and the UEDT complement each other. For *Test 1*, however, the null hypothesis is unable to be rejected for both the PAM and ARDL specifications for Italy, Spain and Sweden and for all three specifications for Belgium; suggesting that APR may well 'dominate' the UEDT.

Turning to the panel data results, the null hypothesis is rejected for both tests for all three specifications – clearly suggesting that there is role for both APR and UEDT, via the time dummies.

Overall the results generally imply there is evidence that APR 'add value' to the UEDT and vice versa; suggesting that there might be a role for both when estimating OECD energy demand models. That is they are complementary estimation methodologies given that the null hypothesis for *Test 2* is always rejected and *Test 1* is rejected in the majority of cases, including all three specifications for the panel data; although there is a hint that for some countries APR might be an alternative for the UEDT.

5. Concluding remarks

This paper has developed a framework to determine whether APR and a non-linear UEDT are complements or substitutes when estimating energy demand functions. The tests outlined have been applied to a sample of 17 OECD countries over the period 1960 to 2004 using both single time-series and panel data estimation. When the countries are grouped as a panel (assuming homogeneity of income and price responses across all countries), all tests for all specifications reject the null hypotheses; clearly showing that there is a role for APR and

UEDT (represented by time dummies). In other words APR and UEDT complement each other when modelling OECD energy demand as a whole.

For the time series tests for the individual countries, again the null hypotheses are on the whole rejected, suggesting that there is a role for APR and a non-linear UEDT. The two approaches appear to complement each other when modelling OECD energy demand for individual countries; although, for some specifications for a small number of countries there is a hint that an APR might dominate an UEDT – suggesting that an APR might be an alternative in a small number of instances.

The implications of these results are that changes in energy prices may well induce asymmetric changes in the derived demand for energy depending upon whether the price falls, rises or rises above a previous maximum. Equally, the derived demand for energy may well *also* be driven by exogenous factors such as improvements in the efficiency of the capital and appliance stock, government regulations, socio-economic factors, etc. Consequently, it is vital that energy demand modellers should not assume at the outset that one method is superior to the other given the evidence presented here. Furthermore, if energy demand modellers do assume one or other approach then it may well lead to misleading and biased estimates. Therefore, the analysis undertaken here strongly suggests that when estimating energy demand functions a general model allowing for APR and UEDT should initially be estimated and only if accepted by the data should a more restrictive specification be adopted.[15]

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[15] Although, this agrees with the view of 'letting the data speak', it should still be recognised that when actually 'searching' for the preferred specification modellers will still need to be guided by economic intuition and theory, as advocated by Adeyemi and Hunt (2007).

Given the results obtained here, further research will apply the testing structure and estimate the 'preferred' energy demand specification for specific group of countries and/or individual countries. In addition, other problems will also be addressed and if possible tested. Several authors, including Ryan and Plourde (2002) and Griffin and Schulman (2005), have identified potential flaws in the price decomposition used here to model asymmetry; in particular the reliance on the old maximum price which is dependent on the starting point of the data. Future work should therefore consider (and preferably test statistically) alternative approaches to decomposing prices (and perhaps income). In addition, the assumption of homogeneity of income and price responses across countries when using panel data is arguably too restrictive (at least as an initial assumption) and a more heterogeneous approach (as the initial general model) should also be considered and if possible tested accordingly.

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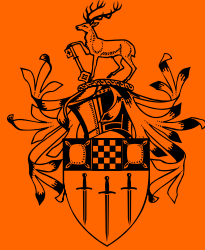
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