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Accounting for asymmetric price responses and underlying energy demand trends in OECD industrial energy demand

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ACCOUNTING FOR ASYMMETRIC PRICE RESPONSES AND UNDERLYING ENERGY DEMAND TRENDS IN OECD INDUSTRIAL ENERGY DEMAND

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ABSTRACT

This paper explores the way technical progress and improvements in energy efficiency are captured when modelling OECD industrial energy demand. The industrial sectors of the developed world involve a number of different practices and processes utilising a range of different technologies. Consequently, given the derived demand nature of energy, it is vital that when modelling industrial energy demand the impact of technical progress is appropriately captured. However, the energy economics literature does not give a clear guide on how this can be achieved; one strand suggests that technical progress is ‘endogenous’ via asymmetric price responses whereas another strand suggests that it is ‘exogenous’. More recently, it has been suggested that potentially there is a role for both ‘endogenous’ and ‘exogenous’ technical progress and consequently the general model should be specified accordingly.

This paper therefore attempts to model OECD industrial energy demand using annual time series data over the period 1962 -2010 for 15 OECD countries. Using the Structural Time Series Model framework, the general specifications allow for both asymmetric price responses (for technical progress to impact endogenously) and an underlying energy demand trend (for technical progress and other factors to impact exogenously, but in a non-linear way). The results show that almost all of the preferred models for OECD industrial energy demand incorporate both a stochastic underlying energy demand trend and asymmetric price responses. This gives estimated long-run income elasticities in the range of 0.34 to 0.96; long-run price-maximum elasticity in the range of -0.06 to -1.22; long-run price-recovery elasticity in the range of 0.00 to -0.71; and long-run price-cut elasticity in the range of 0.00 to -0.13. Furthermore, the analysis suggests that when modelling industrial energy demand there is a place for ‘endogenous’ technical progress and an ‘exogenous’ underlying energy demand trend; consequently, it is argued that, any modelling strategy should start by including both and only imposing restrictions if accepted by the data.

JEL Classifications: C32, C33, C51, C52, L60, Q41.

Key Words: OECD industrial energy demand, Asymmetric Price Responses (APR), Underlying energy demand trend (UEDT)

Accounting for asymmetric price responses and underlying energy demand trends in OECD industrial energy demand[#]

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1. Introduction

This paper explores the way technical progress and improvements in energy efficiency are captured when modelling OECD industrial energy demand. The industrial sectors of the developed world involve a number of different practices and processes that utilise a range of different technologies. Consequently, it is vital that when modelling industrial energy demand the impact of technical progress is appropriately considered, given the derived demand nature of energy. The level of technology at any time is dependent on innovation, which is dependent on a combination of endogenous and exogenous factors. However, the energy economics literature does not give a clear guide on how this can be achieved given the debate on the best way to account for technical change in energy demand models.

'technical progress is endogenous'

One strand of the literature suggests that technical progress should be incorporated endogenously via prices. Kouris (1983a and 1983b) argued that whatever factors are driving technical progress it is unlikely that when using time series data a simple deterministic time

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trend will adequately capture the underlying processes. Furthermore, Kouris (1983a and 1983b) suggests that unless certain engineering data[1] could be found to proxy technical progress then it is better to model it endogenously through price and incomes *without* an explicit variable attempting to capture any exogenous impact of technical progress. In addition, Walker and Wirl (1993) argued that technical change leading to an improvement in energy efficiency is endogenous since it is induced by sustained price rises.

Consistent with this ethos, subsequent work, both in a time series context (such as Dargay, 1992 and Huntington, 2010) and a panel context (such as Gately and Huntington, 2002 and Agnolucci, 2009) decomposed the energy price variable into the asymmetric components that separately measure the impact of prices above the previous maximum ($p_{\max}$ for short), a price recovery below the previous maximum (p_{rec} for short), and a price cut (p_{cut} for short)[2] in order to capture any endogenous impact of technical progress. This commonly used methodology was initially proposed by Wolffram (1971) and later clarified by Houck (1977). In this approach, a segmentation procedure is used to separate the independent price variable into increasing, recovery and decreasing segments, thereby allowing the individual estimation of the impact of the variable when it is increasing, recovering or decreasing. The idea being that increasing energy prices (particularly above any $p_{\max}$) induces technical progress and more energy efficient processes, whereas when the energy price falls these advances are not reversed – hence the expectation of a different response to $p_{\max}$, p_{rec} and p_{cut} .

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[1] For the industrial sector he suggests that something like 'the energy efficiency of a standard boiler' might be appropriate – but in reality such data is difficult to obtain over time in a consistent way across countries.

[2] A full description of the decomposition method is provided in Gately and Huntington (2002) and explained further below.

‘technical progress is exogenous’

Developing in parallel to this, an alternative strand of literature, argues that technical progress should be incorporated exogenously in energy demand models. Despite the arguments by Kouris (1983a and 1983b) discussed above, in (symmetric) time series estimation of energy demand models the most common way to capture exogenous technical progress was via a simple linear time trend. For example, Beenstock and Willcocks (1981, 1983) suggested that, although not a satisfactory method, the use of a time trend is better than just ignoring the issue. This debate was picked up by Hunt et al (2003a & 2003b) who also argued that a linear trend is an inadequate way to capture technical progress but arguing that there is still a need to capture exogenous effects that can be achieved via a stochastic trend – referred to as the underlying energy demand trend (UEDT). However, according to Hunt et al (2003a and 2003b), the UEDT includes more than just exogenous technical progress; it also includes exogenous change caused by such things as habit persistence, changes in values and lifestyles, changes in economic structure, changes in building and environmental regulations, etc.

Parallel to this, Griffin and Schulman (2005) questioned the price decomposition approach for modelling endogenous technical progress in a panel context. They argued that the price decomposition used by Gately and Huntington (2002) and others only acts as a proxy for energy-saving technical change and therefore the way to model energy in panel data models is via symmetric price models and time dummies. This is arguably analogous to the UEDT approach in time series data since it results in a ‘non-linear’ exogenous impact – that should pick up technical progress, but also other important exogenous factors suggested by Hunt et al. (2003a and 2003b) and Hunt and Ninomiya (2003).

'technical progress might be endogenous and/or exogenous'

Recently, it has been suggested that potentially there is a role for both and the general model should be specified accordingly. Huntington (2006) challenged the Griffin and Schulman (2005) argument showing that in a panel data context, statistically there may well be a role for both asymmetric price responses (APR) and time dummies. In other words, there is role for trying to capture the 'endogenous' technical progress via decomposed prices *and* exogenous technical progress (or the wider concept of a UEDT) via time dummies. Following the Huntington (2006) approach, Adeyemi and Hunt (2007) argue that when estimating energy demand using panel data then the general model should include both APR and a UEDT, and only if accepted by the data should a more restricted model be chosen. Furthermore, Adeyemi et al. (2010) undertake a range of statistical testing in both a time series and panel context and conclude that in general there is a role for both 'endogenous' technical progress via APR and an 'exogenous' UEDT via either time dummies (in a panel context) or a stochastic trend (in a time series context).

Given the lack of direction in the literature, an objective of this paper is to account for APR *and* technical progress (or, to be more precise, the wider concept of a UEDT) in time series models of industrial energy demand. As background to this, Table 1 summarises a selection of the literature on technical progress and price response asymmetry, focussing on single-equation models and those studies analysing aggregate energy and/or oil.[3] This shows that the majority of the studies surveyed have studied OECD and G7 countries, while the frequency of data is typically annual. The modelling technique employed is usually dynamic and non-linear through the autoregressive distributed lag model (ARDL), structural time series model (STSM), Koyck lag model and non-linear fixed-effect panel data model.

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[3] Table 3 does not cover every possible paper in the area but focusses on those papers felt to be more influential and/or often cited.

Table 1: Selection of previous studies on Asymmetry/Technical Progress

Study	Types of energy	Sectors	Country /Region	Functional form	Nature of specification	Estimation method	Treatment of technical change	Data used	Estimated LR Elasticities
Beenstock & Willcocks (1981)	Aggregate energy	IND; RES.	OECD	Log-linear	ECM	Least-squares	Deterministic trend	Annual (Time series) 1950-1978	Income = 1.78 Price = -0.06
Dargay (1990)	Oil	WE; TRANS; RES.	UK	Log-linear	ECM Decomposed prices	Least-squares	APR; deterministic trend	Annual (Time series) 1960-1988	Income (Sym) = 1.03 Income (Asy) = 1.53 P+ = -0.63 P- = 0.00 P = -0.57
Dargay (1992)	Aggregate energy	TRAN.	France, Germany, and the UK	Log-linear	ECM Decomposed prices	Least-squares	APR	Annual (Time series) 1962-1988	Income = 1.29 to 1.71 Price-max = -0.44 to -1.50 Price-rise = -0.10 to -0.80 Price-fall = -0.02 to -0.45
Jones (1994)	Aggregate energy	WE.	G-7 countries	Log-linear	ARDL	Non-linear least-squares	Deterministic trend	Annual (Panel) 1960-1990	Income = 1.23 Price = -0.69
Dargay & Gately (1995)	Oil	WE (Non-TRANS).	11 OECD countries	Log-linear	Koyck lag Decomposed prices	Non-linear least-squares	APR	Annual (Panel) 1970-1991	Income (Sym) = 1.00 Price = -2.10 Income (Asy) = 1.09 Price-max = -0.76 Price-cut = -0.04 Price-rec = -0.54
Dargay & Gately (1997)	Aggregate energy	TRANS	11-region OECD	Log-linear	Koyck lag Decomposed prices	Non-linear least-squares	APR	Annual (Panel) 1962-1990	Income (Sym) = 0.68 Price = -0.42 Income (Asy) = 1.13 Price-max = -0.60 Price-rec = -0.13 Price-cut = -0.13
Hass, et al. (1998)	Natural gas	RES	9 OECD countries	Log-linear	ARDL Decomposed prices	Non-linear least-squares	Deterministic trend; APR	Annual (Panel) 1970-1995	Income = 0.11 to 3.51 Price-max = -0.14 to -0.85 Price-rec = -1.81 to 1.37 Price-cut = -0.22 to -1.44
Gately & Huntington (2002)	Aggregate energy	WE	96 OECD/ non-OECD countries.	Log-linear	Koyck lag Decomposed prices	Non-linear least-squares	APR	Annual (Panel) 1971-1997	Income = 0.59 Price = -0.24

Table 1:Continued

Hunt et al (2003a)	Aggregate energy	WE RES; MFG; TRANS	UK	Log-linear	ARDL	Maximum likelihood / Kalman filter	Stochastic trend	Quarterly (Time series) 1971Q1-1995Q4	Income = 0.72 Price = -0.20
Hunt & Ninomiya (2003b)	Oil	TRANS	UK & Japan	Log-linear	ARDL	Maximum likelihood / Kalman filter	Stochastic trend	Quarterly (Time series) 1972Q1-1995Q4	Income = 1.08 & 0.80 Price = -0.08 & -0.12 (For Japan & UK respectively.)
Hunt & Ninomiya (2005)	Aggregate energy	WE	Japan	Log-linear	ARDL	Maximum likelihood / Kalman filter	Stochastic trend;	Annual (Time series) 1887-2001	Income = 1.06 Price = -0.18
Griffin & Schulman (2005)	Aggregate energy	WE	16 OECD countries.	Log-linear	Koyck Lag Decomposed prices	Non-linear least-squares	Time dummies	Annual (Panel) 1961-1999	Income = 0.41 Price = -0.57
Dimitropoulos et al (2005)	Aggregate energy	WE, RES, MFG, TRANS.	UK	Log-linear	ARDL	Maximum likelihood / Kalman filter	Stochastic trend	Annual (Time series) 1967-1999	Income = 0.70 Price = -0.16
Adeyemi & Hunt (2007)	Aggregate energy	IND.	15 OECD countries.	Log-linear	Koyck Lag Decomposed prices	Non-linear least-squares	APR; Time dummies	Annual (Panel) 1962-2003	Income = 0.78 Price-max = -0.52 Price-rec = -0.68 Price-cut = -0.30
Agnolucci (2009)	Aggregate energy	IND.	UK & Germany	Log-linear	ARDL	Non-linear least-squares	Deterministic trend	Annual (Panel) 1978-2004	Income = 0.52 Price = -0.64
Huntington (2010)	Oil	WE.	USA	Log-linear	ARDL, Decomposed prices	Non-linear least-squares	APR; Time dummies	Annual (Time series) 1950-2005	Income = 1.20 Price-max = 0.00 to -1.54 Price-rec = 0.00 Price-cut = 0.00
Dargay and Gately (2010))	Total Oil[4]	OECD WE	OECD	Log-linear	Koyck Lag Decomposed prices	Non-linear least-squares	APR – no time dummies	Annual (Time series) 1971-2008	Income = 0.80 Price-max = -0.60 Price-rec = -0.20 Price-cut = -0.29

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[4] This just one of a number of different oil and oil products demand estimates for a range of different world regions.

Table 1 also shows that not surprisingly given the different data sets, fuels and sectors used there is some variation in previous estimated elasticities. Using data for OECD countries over the period 1950 – 1978, Beenstock and Willcocks (1981) estimated long-run income and price elasticities to be 1.78 and -0.06 respectively. Dargay and Gately (1995) obtained a similar long-run income estimate for non-transport oil demand in eleven OECD countries of 1.09 and a long-run $p_{\max}$ elasticity of -0.76. When comparing the results of models employing the use of asymmetric price responses, it is clear that the long-run estimates for the $p_{\max}$, p_{rec} and p_{cut} give very different results. This is probably due to the use of different data sets with different start dates that affect the associated decomposed price series. Long-run price and $p_{\max}$ elasticities therefore range from -0.06 to -2.10 and -0.14 to -1.50 respectively, while long-run income elasticity range from 0.11 to 3.51. For instance, while Dargay (1990) estimates long-run income and $p_{\max}$ elasticities of 1.53 and -0.63 respectively, Dargay and Gately (1997) obtained long-run income and $p_{\max}$ elasticities of 1.13 and -0.60 respectively. Furthermore, Dargay and Gately (2010) find, for total OECD oil demand, a long-run income elasticity of 0.80 and long-run $p_{\max}$, p_{rec} and p_{cut} elasticities of -0.60, -0.20, -0.29 respectively. These results give an indication of the variety of values that have been obtained with the use of the different energy sources, sectors and data sets.[5]

The methodology employed in this paper therefore allows for a general model with both APR and a stochastic UEDT. The idea is to examine the importance of incorporating a UEDT into a

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[5] Which is probably to be expected, but it is worth noting that the $p_{\max}$, p_{rec}, and p_{cut}, elasticities often do not conform to that expected *a priori* (as explained further below in the methodology section). It is also worth noting in this respect that there has been some debate in the literature about the use of the $p_{\max}$, p_{rec}, and p_{cut} decomposition because of the inconsistencies that may result from having to rely on the start dates of the data; see Adofo et al. (2013) for further discussion.

model of industrial energy demand with APR as explained in detail in Section 2. Section 3 presents the results and Section 4 summarises and concludes.

2. Methodology

In order to consider fully the effect of APR, four 'general' models of asymmetry/symmetry are considered: '*Full Asymmetry (FA)*', '*Restricted Asymmetry I (RAI)*', '*Restricted Asymmetry II (RAII)*', and '*Symmetry (S)*'. These are described below.

'FA Model'

The most general model specification for modelling OECD industrial energy demand used in this paper incorporates ARP and a stochastic UEDT with Autoregressive Distributed Lag of order one [or ARDL(1) for short], represented by:

$$\begin{aligned} e_t = {} & UEDT_t + \alpha_0 y_t + \alpha_1 y_{t-1} + \gamma_0 p_{\max,t} + \gamma_1 p_{\max,t-1} + \pi_0 p_{rec,t} \\ & + \pi_1 p_{rec,t-1} + \delta_0 p_{cut,t} + \delta_1 p_{cut,t-1} + \lambda e_{t-1} + \varepsilon_t \end{aligned} \tag{1}$$

Where:

e_t = natural logarithm of industrial energy consumption in year t;

y_t = natural logarithm of the industrial output index in year t;

$p_{\max,t}$ = $\max(p_1,...,p_t)$, representing the natural logarithm of the maximum historical industrial energy price in year t;

$p_{rec,t}$ = $\sum_{t=1}^{t} \max\{0,(p_t - p_{t-1}) - (p_{\max,t} - p_{\max,t-1})\}$, representing the cumulative sub-maximum increases in the natural logarithm of the industrial energy price in year t, (monotonically non-decreasing, $p_{rec,t} \geq 0$);

$p_{cut,t}$ = $\sum_{t=1}^{t} \min\{0,(p_t - p_{t-1}) - (p_{\max,t} - p_{\max,t-1})\}$, representing the deceases in the logarithm of the industrial energy price in year t, (monotonically non-increasing, $p_{cut,t} \leq 0$);

p_t = $p_{\max,t} + p_{rec,t} + p_{cut,t}$, the logarithm of the industrial energy price in year *t*,[6]

$UEDT_t$ = the UEDT (discussed further below);

ε_t = disturbance term which is $NID(0, \sigma_\varepsilon^2)$;

t = 1962-2010;

α_i = y_{t-i} coefficients, *i= 0, 1*;

γ_i = $p_{\max,t-1}$ coefficients, *i= 0, 1*;

π_i = $p_{rec,t-1}$ coefficients, *i= 0, 1*;

δ_i = $p_{cut,t-1}$ coefficients, *i= 0, 1*;

λ = e_{t-1} coefficient;

$\alpha^* = \dfrac{\alpha_0 + \alpha_1}{1-\lambda}$ = long-run income elasticity;

$\gamma^* = \dfrac{\gamma_0 + \gamma_1}{1-\lambda}$ = long-run $p_{\max}$ elasticity;

$\pi^* = \dfrac{\pi_0 + \pi_1}{1-\lambda}$ = long-run p_{rec} elasticity; and

$\delta^* = \dfrac{\delta_0 + \delta_1}{1-\lambda}$ = long-run p_{cut} elasticity.

Furthermore, it is expected *a priori* that energy demand falls more rapidly when energy prices rise than it would increase when energy prices fall, and falls most rapidly when a new maximum energy price is reached (similar to Gately and Huntington, 2002, and Dargay and Gately, 2010).

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[6] Gately and Huntington (2002) include p_1 in their decomposition so that $p_t = p_1 + p_{\max t} + p_{rec,t} + p_{cut,t}$, where the components are defined as: p_1 = logarithm of price in the starting year, t=1 and $p_{\max,t} = \sum_{t=1}^{t} \{\max(p_1,..., p_t) - \max(p_1,..., p_{t-1})\}$ which represents the cumulative increases in the logarithm of the maximum historical price, monotonically non-decreasing, $p_{\max,t} \geq 0$. $p_{rec,t}$ and $p_{cut,t}$ have the same definition as those in the text above. This is slightly different to the decomposition used here given the constraints in models RAI, RAII, and S (i.e. so that in S below p_t is equal to $p_{\max t} + p_{rec,t} + p_{cut,t}$ and not $p_1 + p_{\max t} + p_{rec,t} + p_{cut,t}$. However, it is important to note that the estimated income and price elasticities and the shape of the estimated UEDTs are the same irrespective of which decomposition is used.

In other words, it is expected that the long-run p_{rec} elasticity will be no greater (in absolute terms) than the long-run $p_{\max}$ elasticity and that the long-run p_{cut} elasticity will be no greater (in absolute terms) than the long-run p_{rec} elasticity; i.e. $|\gamma^*| \geq |\pi^*| \geq |\delta^*|$. In estimating the models, considering this theoretical *a priori* expectation is seen as crucial as discussed further below.

'RAI Model'

When modelling for the individual countries and it proves difficult to find statistically significant coefficients for the asymmetric price terms and/or where the estimated long-run coefficients do not conform to the *a priori* expectation that $|\gamma^*| \geq |\pi^*| \geq |\delta^*|$, then a simpler general model is explored where the decomposition consists of only price rises (p_{rise} for short) and p_{cut}. Therefore, the restrictions that $\theta_0 = \gamma_0 = \pi_0$ and $\theta_1 = \gamma_1 = \pi_1$ are imposed so that the general ARDL(1) model in equation (1) becomes:

$$e_t = UEDT_t + \alpha_0 y_t + \alpha_1 y_{t-1} + \theta_0 p_{rise,t} + \theta_1 p_{rise,t-1} + \delta_0 p_{cut,t} + \delta_1 p_{cut,t-1} + \lambda e_{t-1} + \varepsilon_t \quad (2)$$

Where e_t, y_t, $p_{cut,t}$, $UEDT_t$, α_i, δ_i, λ, ε_t, t, α^*, and δ^* are as defined above,

$p_{rise,t}$ = $p_{\max,t} + p_{rec,t}$ representing the cumulative rise in the natural logarithm of historical industrial real energy prices in year *t*;

θ_i = $p_{rise,t-1}$ coefficients, *i= 0, 1*; and

$\theta^* = \dfrac{\theta_0 + \theta_1}{1-\lambda}$ = long-run p_{rise} elasticity.[7]

Here the *a priori* expectation is that the long-run p_{cut} elasticity will be no greater (in absolute terms) than the long-run p_{rise} elasticity, $|\theta^*| \geq |\delta^*|$. In other words, energy demand is expected to fall more rapidly when energy prices rise than it would increase when energy prices fall.

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[7] Which effectively imposes the restriction in Equation (1) that the long-run $p_{\max}$ elasticity is equal to the long-run p_{rec} elasticity, i.e. $\theta^* = \gamma^* = \pi^*$

'RAII Model'

Where this also proves difficult to find statistically significant coefficients for the asymmetric price terms and/or where the estimated long-run coefficients do not conform to the *a priori* expectation that $|\theta^*| \geq |\delta^*|$, then a further simpler general model is explored. Here the price decomposition consists of only $p_{\max}$ and price changes (p_{change} for short). Therefore, the restrictions that $\psi_0 = \pi_0 = \delta_0$ and $\psi_1 = \pi_1 + \delta_1$ are imposed so that the general ARDL(1) model in equation (1) becomes:

$$e_t = UEDT_t + \alpha_0 y_t + \alpha_1 y_{t-1} + \gamma_0 p_{\max,t} + \gamma_1 p_{\max,t-1} + \psi_0 p_{change,t} + \psi_1 p_{change,t-1} + \lambda e_{t-1} + \varepsilon_t \quad (3)$$

Where e_t, y_t, $p_{max,t}$, $UEDT_t$, α_i , γ_i , λ , ε_t , t, α^* , and γ^* are as defined above,

$p_{change,t}$ = $p_{rec,t} + p_{cut,t}$ representing the cumulative decrease and rise in the natural logarithm of historical industrial real energy prices below the previous maximum in year *t*;

ψ_i = $p_{change,t-1}$ coefficients, *i= 0, 1*; and

$\psi^* = \dfrac{\psi_0 + \psi_1}{1-\lambda}$ = long-run p_{change} elasticity.[8]

Here the *a priori* expectation is that the long-run p_{change} elasticity will be no greater (in absolute terms) than the long-run $p_{\max}$ elasticity, $|\gamma^*| \geq |\psi^*|$. In other words, energy demand is expected to fall more rapidly when energy prices rise to a new maximum than it would increase when energy prices falls or decrease when energy prices rise (below a previous maximum)

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[8] Which effectively imposes the restriction in Equation (1) that the long-run p_{rec} elasticity is equal to the p_{cut} elasticity, i.e. $\psi^* = \pi^* = \delta^*$

'S Model'

Finally, where it proves impossible to obtain an APR specification using any of the three specifications above, Equations (1), (2) and/or (3), an even more restrictive general symmetric price response model is specified. The price variable (*p*) is no therefore no longer decomposed, with the restrictions $\varphi_0 = \gamma_0 = \pi_0 = \delta_0$ and $\varphi_1 = \gamma_1 = \pi_1 + \delta_1$ imposed so that the general ARDL(1) model in equation (1) becomes:

$$e_t = UEDT_t + \alpha_0 y_t + \alpha_1 y_{t-1} + \varphi_0 p_t + \varphi_0 p_{t-1} + \lambda e_{t-1} + \varepsilon_t \qquad (4)$$

Where e_t, y_t, $UEDT_t$, α_i, λ, ε_t, t, and α^* are as defined above,

$p_t \quad = \quad p_{\max,t} + p_{rec,t} + p_{cut,t}$; and

$\varphi^* = \dfrac{\varphi_1 + \varphi_2}{1-\lambda}$ = long-run (symmetric) *p* elasticity.[9]

'Exogenous UEDT (μ_t)'

For all equations above (1) – (4) the UEDT is initially assumed to follow a stochastic process and can be estimated by the STSM as follows:

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

$$\beta_t = \beta_{t-1} + \xi_t \qquad \xi_t \sim NID(0, \sigma_\xi^2) \qquad (6)$$

where μ_t and $\beta_{t\,t}$ are the level and slope of the UEDT respectively; η_t and ξ_t are the mutually uncorrelated white noise disturbances with zero means and variances σ_η^2 and σ_ξ^2 respectively. The nature of the UEDT depends on the zero restrictions imposed on the level, slope and the key *hyper-parameters* σ_η^2 and σ_ξ^2. Moreover, irregular, level and slope interventions are included to aid the passing of the diagnostic tests, in particular to ensure that the normality of the auxiliary

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[9] Which effectively imposes the restriction in Equation (1) that the long-run $p_{\max}$ elasticity is equal to the p_{rec} elasticity is equal to the p_{cut} elasticity, i.e. the price elasticities are symmetric: $\varphi^* = \gamma^* = \pi^* = \delta^*$

residuals (irregular, level and slope) is maintained (Harvey and Koopman, 1992). These interventions can give information about important breaks and structural changes at certain dates within the estimation period. Therefore, similar to Dilaver and Hunt (2011) the UEDT is given by

$$UEDT_t = \mu_t + \text{irregular interventions} + \text{level interventions} + \text{slope interventions} \quad (7)$$ [10]

Furthermore, as part of the testing strategy Likelihood Ratio (LR) tests are undertaken to ensure that σ_η^2 and/or σ_ξ^2 are significantly different from zero. If, it is found that both σ_η^2 and σ_ξ^2 are not significantly from zero (in any of the above models) then the restriction $\sigma_\eta^2 = \sigma_\xi^2 = 0$ is imposed. This leaves two possible outcomes, stochastic (St) or deterministic (D) for each of the models detailed above.

The estimated model for each country is therefore initially *Model FA* [consisting of Equations (1), (5) and (6)]. If, as stated above, it is not possible to obtain statistically significant price coefficients and or they do conform to *a priori* economic intuition then *Model RAI* is estimated instead [consisting of Equations (2), (5) and (6)]. If this also proves difficult, *Model RAII* is estimated [consisting of Equations (3), (5) and (6)]. However, if all of these prove difficult, the symmetric *Model S* is estimated [consisting of Equations (4), (5) and (6)].

For all models, the estimation is by the maximum likelihood function coupled with the Kalman filter using the software package STAMP 8.10 (Koopman et al., 2007). Following a general-to-specific strategy, the coefficients of insignificant variables and hyper-parameters are gradually deleted according to goodness of fit criteria and ensuring that an exhaustive list of diagnostic tests for the equation residuals are passed, and the auxiliary residuals do not suffer from non-

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[10] If no interventions are identified then $UEDT_t$ is equal to μ_t.

normality to arrive at the final preferred specification for each model. From this, a preferred specification for *Model FA* with a stochastic or deterministic trend (*FASt* or *FAD*) is obtained. If this is not possible, the preferred specification for *Model RAI* with a stochastic or deterministic trend (*RAISt* or *RAID*) is obtained. If this is not possible, the preferred specification for *Model RAII* with a stochastic or deterministic trend (*RAIISt* or *RAIID*) is obtained. However, if none of these proves possible, the preferred specification for *Model S* with a stochastic or deterministic trend (*SSt* or *SD*) is obtained.

3. Empirical results

3.1 Data

The time series data used in the analysis consists of 15 OECD countries (Austria, Belgium, Canada, France, Greece, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK, and the USA) and covers the period from 1962 to 2010. Each country's aggregate industrial energy consumption in thousand tonnes of oil equivalent (ktoe) and the index of industrial output (2005=100) over the whole period 1962 – 2010 come from IEA(2012). Whereas the index of industrial real energy prices (2005=100) is only available for the period from IEA (2013) for the period 1978 – 2010. Consequently, this is spliced with an index for each country derived from data in Baade (1981) calculated from different fuel price indices:[11] the real industrial gas price, the real industrial coal price, and the real industrial electricity price weighted by their fuel consumption shares.[12] This produces industrial real aggregate energy price indices for each country in 1972 prices (1972 = 100) over the period

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[11] This source was used in a similar way by Prosser (1985) to calculate real price indices for the whole economy.

[12] Arguably, the energy price indices for 1962-1980 would benefit from the inclusion of prices of oil products, but a lack of consistent data across countries precludes its use.

1962 to 1980. The two series (1962 – 1980; 1972=100) and (1978 – 2010; 2005=100) are subsequently spliced using the ratio from the overlap year 1978 to obtain the series for the whole period 1962 to 2010 at 2005 prices (2005=100).

3.2 Estimation results

Following the general-to-specific strategy outlined above, for each of the 15 OECD countries, the different models also outlined above, are estimated and tested in order to obtain the preferred models given in Table 2. This shows that in general, most of the preferred models are free of any misspecification problems, passing almost all diagnostics tests. The exceptions being: Greece (where the is a small problem of heteroscedasticity); Japan (where the model shows some instability in the predictive failure test); and Norway (where the Box-Ljung test suggests that there might be a problem with serial correlation, but the correlation coefficients up to three lags do not suggest there is a problem).[13] Table 2 also shows that for all countries the estimated UEDT is found to be stochastic, with the likelihood ratio tests clearly showing that the restrictions of a setting the appropriate hyper-parameters to zero for a deterministic trend are rejected for all countries.

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[13] In fact, Norway was a difficult country to model often with non-convergent problems and the coefficient for $p_{\max}$ is very insignificant but is retained in order to avoid greater problems with the diagnostic tests. Similarly, two interventions for Switzerland are not significant but are retained to ensure all the diagnostic tests are passed.

Table 2:Preferred models of industrial energy demand

	Austria	**Belgium**	**Canada**	**France**	**Greece**
Model	*FASt (RAIISt)*	*FASt (RAIISt)*	*SSt*	*FASt*	*FASt (RAIISt)*
Estimated Coefficients					
λ	-	-	-	-	-
α_0	0.339***	0.922***	0.462***	0.459***	0.750***
α_1	-	-	-	-	-
γ_0	-1.2231***	-0.515***	n/a	-	-0.513**
γ_1	-	-	n/a	-0.612***	-
θ_0	n/a	n/a	n/a	n/a	n/a
θ_1	n/a	n/a	n/a	n/a	n/a
π_0	-	-	n/a	-0.267**	-
π_1	-	-	n/a	-	-
δ_0	-	-	n/a	-	-
δ_1	-	-	n/a	-	-
ψ_0	-	-	n/a	n/a	-
ψ_1	-	-	n/a	n/a	-
φ_0	n/a	n/a	-	n/a	n/a
φ_1	n/a	n/a	-0.103**	n/a	n/a
LR elasticity estimates					
α* (income)	0.34	0.92	0.46	0.46	0.75
γ* (price-max)	-1.22	-0.52	-0.10	-0.61	-0.51
π* (price-rec)	0.00	0.00	-0.10	-0.27	0.00
δ* (price-cut}	0.00	0.00	-0.10	0.00	0.00
Hyperparameters					
Irregular	0.000150	0.000496	0.000238	0.000030	0.000000
Level	0.000247	0.000469	0.000439	0.000891	0.001671
Slope	0.000036	0.000016	-	-	0.000063
Nature of Trend	Local trend	Local trend	Local level with drift	Local level with drift	Local trend
Interventions	Irr1964***, Lvl1967***, Lvl1970***, Irr1997***.	Lvl1968**, Irr1983**, Lvl2000***, Lvl2002***.	Lvl1975***, Slp1980***.	Irr1970**, Slp1971***.	Irrl1966***, Irr1968***, Irr1999*, Lvl2009***.
Goodness of fit					
p.e.v.	0.000592	0.001258	0.000745	0.000815	0.001698
AIC	-7.065	-6.310	-6.916	-6.786	-6.011
R^2	0.982	0.939	0.987	0.949	0.994
R_d^2	0.749	0.779	0.732	0.749	0.795
Residual Diagnostics					
Std Error	0.024	0.035	0.027	0.029	0.041
Normality	2.06	0.56	0.66	0.81	0.99
$H_{(h)}$	$H_{(13)} = 0.74$	$H_{(13)} = 0.81$	$H_{(14)} = 0.84$	$H_{(13)} = 1.28$	$\mathbf{H_{(13)} = 2.39^*}$
$r_{(1)}$	-0.05	-0.06	0.04	-0.05	0.08
$r_{(2)}$	0.02	-0.08	0.02	-0.10	-0.11
$r_{(3)}$	0.12	-0.03	-0.09	-0.12	-0.19
DW	2.07	1.98	1.92	2.00	1.73
$Q(_{p,\,d})$	$\chi^2_{(5)} = 6.67$	$\chi^2_{(5)} = 0.65$	$\chi^2_{(5)} = 4.53$	$\chi^2_{(5)} = 5.67$	$\chi^2_{(5)} = 5.00$
Auxiliary residuals:					
Normality – Irregular	3.02	0.49	1.80	0.23	2.08
Normality – Level	1.33	1.50	0.10	0.64	0.66
Normality – Slope	0.35	0.32	-	-	1.49
Pred. Failure $\chi^2_{(f)}$	$\chi^2_{(5)} = 1.67$	$\chi^2_{(5)} = 5.72$	$\chi^2_{(5)} = 6.47$	$\chi^2_{(5)} = 4.71$	$\chi^2_{(4)} = 5.92$
LR test $\chi^2_{(R)}$	$\chi^2_{(2)} = 68.8^{***}$	$\chi^2_{(2)} = 24.9^{***}$	$\chi^2_{(1)} = 27.4^{***}$	$\chi^2_{(1)} = 27.9^{***}$	$\chi^2_{(2)} = 38.4^{***}$

Table 2: Continued

	Italy	**Japan**	**Netherlands**	**Norway**	**Portugal**
Model	*FASt*	*RAIISt*	*RAISt*	*FASt (RAIISt)*	*RAIISt*
Estimated Coefficients					
λ	-	-	-	-	-
α_0	0.664***	0.457***	0.826***	0.399***	0.504***
α_1	-	-	-	-	0.199*
γ_0	-0.194**	-0.457***	n/a	**-0.058**	-
γ_1	-0.295***	-	n/a	-	-0.465***
θ_0	n/a	n/a	-	n/a	n/a
θ_1	n/a	n/a	-0.146*	n/a	n/a
π_0	-0.132*	n/a	n/a	-	n/a
π_1	-	n/a	n/a	-	n/a
δ_0	-	n/a	-	-	n/a
δ_1	-	n/a	-	-	n/a
ψ_0	n/a	-0.135*	n/a	-	-
ψ_1	n/a	-	n/a	-	-0.121**
φ_0	n/a	n/a	n/a	n/a	n/a
φ_1	n/a	n/a	-n/a	n/a	n/a
LR elasticity estimates					
α* (income)	0.66	0.46	0.83	0.40	0.70
γ* (price-max)	-0.49	-0.46	-0.15	-0.06	-0.47
π* (price-rec)	-0.13	-0.13	-0.15	0.00	-0.12
δ* (price-cut}	0.00	-0.13	0.00	0.00	-0.12
Hyperparameters					
Irregular	0.000107	0.000000	0.000922	0.000000	0.000213
Level	-	0.000628	-	0.002291	0.000566
Slope	0.000130	-	0.000223	n/a	-
Nature of Trend	Smooth trend	Local level with drift	Smooth trend	Local level (random walk plus noise)	Local level with drift
Interventions	Irr1966***, Lvl1970***, Lvl1978***, Irr1986***.	Irrl1968***, Slp1969***, Lvl1970***, Lvl2008***.	Lvl1975***, Irr2006***.	Lvl2009***.	Lvl1970***, Irr1990**.
Goodness of fit					
p.e.v.	0.000399	0.000513	0.002224	0.002104	0.000790
AIC	-7.377	-7.167	-5.823	-5.960	-6.776
R^2	0.985	0.990	0.950	0.929	0.997
R_d^2	0.897	0.883	0.707	0.362	0.727
Residual Diagnostics					
Std Error	0.020	0.023	0.047	0.046	0.028
Normality	2.17	0.01	3.75	1.76	0.02
$H_{(h)}$	$H_{(12)} = 1.85$	$H_{(13)} = 0.74$	$H_{(14)} = 0.46$	$H_{(15)} = 1.67$	$H_{(13)} = 1.23$
$r_{(1)}$	0.12	-0.18	-0.00	0.15	-0.07
$r_{(2)}$	0.06	-0.05	-0.01	-0.17	-0.09
$r_{(3)}$	0.13	0.19	-0.14	-0.10	0.14
DW	1.72	2.32	1.96	1.53	2.11
$Q(p, d)$	$\chi^2_{(5)} = 8.53$	$\chi^2_{(5)} = 9.11$	$\chi^2_{(5)} = 8.18$	$\chi^2_{(4)}$ **= 10.93****	$\chi^2_{(5)} = 7.42$
Auxiliary residuals:					
Normality – Irregular	1.85	3.84	1.02	1.80	1.89
Normality – Level	-	0.49	-	1.60	0.39
Normality – Slope	2.04	-	0.98	n/a	-
Pred. Failure $\chi^2_{(f)}$	$\chi^2_{(5)} = 4.54$	$\chi^2_{(4)}$ **= 8.83***	$\chi^2_{(5)} = 5.96$	$\chi^2_{(4)} = 6.15$	$\chi^2_{(5)} = 3.49$
LR test $\chi^2_{(R)}$	$\chi^2_{(1)} = 49.3$***	$\chi^2_{(1)} = 16.0$***	$\chi^2_{(1)} = 8.6$***	$\chi^2_{(1)} = 86.2$***	$\chi^2_{(1)} = 23.0$***

Table 2: Continued

	Spain	**Sweden**	**Switzerland**	**UK**	**USA**
Model	*FASt (RAIISt)*	*SSt*	*FASt (RAIISt)*	*FASt (RAIISt)*	*RAISt*
Estimated Coefficients					
λ	-	-	-	-	-
α_0	0.956***	0.820***	0.492***	0.719***	0.725***
α_1	-	-	-	-0.250**	-
γ_0	-	n/a	-	-	n/a
γ_1	-0.447***	n/a	-0.512***	-0.714***	n/a
θ_0	n/a	n/a	n/a	n/a	-
θ_1	n/a	n/a	n/a	n/a	-0.194***
π_0	-	n/a	-	-	n/a
π_1	-	n/a	-	-	n/a
δ_0	-	n/a	-	-	-
δ_1	-	n/a	-	-	-
ψ_0	-	n/a	-	-	n/a
ψ_1	-	n/a	-	-	n/a
φ_0	n/a	-0.177***	n/a	n/a	n/a
φ_1	n/a	-	n/a	n/a	n/a
LR elasticity estimates					
α* (income)	0.96	0.82	0.49	0.47	0.73
γ* (price-max)	-0.45	-0.18	-0.51	-0.71	-0.19
π* (price-rec)	0.00	-0.18	0.00	0.00	-0.19
δ* (price-cut}	0.00	-0.18	0.00	0.00	0.00
Hyperparameters					
Irregular	0.000000	0.000191	0.000147	0.000240	0.000000
Level	0.001053	0.000620	-	-	0.001512
Slope	-	-	0.000543	0.000083	n/a
Nature of Trend	Local level with drift	Local level with drift	Smooth trend	Smooth trend	Local level (random walk plus noise)
Interventions	Irr1968**, Lvl1969***, Irr1972**, Slp1999***, Lvl2006***.	Slp2009***.	Irr1963***, Irr1973***, Irr1982***, **Irr1984,** **Irr1985**, Irr1999***.	Lvl1991***.	Lvl1967**, Lvl1989***.
Goodness of fit					
p.e.v.	0.000860	0.000866	0.000935	0.000637	0.001357
AIC	-6.651	-6.806	-6.527	-7.07	-6.357
R^2	0.995	0.923	0.948	0.985	0.923
R_d^2	0.909	0.669	0.796	0.737	0.675
Residual Diagnostics					
Std Error	0.029	0.029	0.031	0.025	0.037
Normality	3.33	0.59	0.89	0.34	0.46
$H_{(h)}$	$H_{(13)} = 1.30$	$H_{(14)} = 0.49$	$H_{(13)} = 0.68$	$H_{(14)} = 0.85$	$H_{(14)} = 1.31$
$r_{(1)}$	0.01	0.04	-0.04	-0.04	-0.11
$r_{(2)}$	-0.09	-0.19	-0.05	0.09	0.01
$r_{(3)}$	0.01	-0.14	0.01	0.05	-0.05
DW	1.96	1.79	2.04	2.03	2.06
$Q(_{p,\,d})$	$\chi^2_{(5)} = 6.64$	$\chi^2_{(5)} = 3.97$	$\chi^2_{(5)} = 8.01$	$\chi^2_{(5)} = 4.29$	$\chi^2_{(4)} = 4.11$
Auxiliary residuals:					
Normality – Irregular	0.82	0.11	0.20	0.54	0.50
Normality – Level	1.06	0.18	-	-	0.62
Normality – Slope	-	-	0.69	1.43	n/a
Pred. Failure $\chi^2_{(f)}$	$\chi^2_{(5)} = 2.80$	$\chi^2_{(4)} = 0.93$	$\chi^2_{(5)} = 6.07$	$\chi^2_{(5)} = 5.94$	$\chi^2_{(5)} = 4.84$
LR test $\chi^2_{(R)}$	$\chi^2_{(1)} = 22.6$***	$\chi^2_{(1)} = 35.2$***	$\chi^2_{(1)} = 64.0$***	$\chi^2_{(1)} = 79.6$***	$\chi^2_{(1)} = 27.8$***

Notes for Table 2:

- (i) Estimated models and all tests obtained from the software package STAMP 8.10 (Koopman et al., 2007);
- (ii) ***, **, & * denotes statistical significance at 1%, 5% and 10% respectively;
- (iii) p.e.v. is the prediction error variance and AIC the Akaike information criterion;
- (iv) R^2 is the coefficient of determination and R_d^2 is the coefficient of determination; and
- (v) Normality is the Bowman-Shenton test; approximately distributed as $\chi^2_{(2)}$;
- (vi) *H(h)* is the test for heteroscedasticity, distributed approximately as $F_{(h,h)}$;
- (vii) $r(\tau)$ are the residual autocorrelations at lag τ distributed approximately as $N(0, 1/T)$;
- (viii) DW is the Durbin-Watson statistic;
- (ix) *Q(p,d)* is the Box-Ljung statistic based on the first *p* residuals autocorrelations and distributed approximately as $\chi^2_{(d)}$;
- (x) Pred. Failure $\chi^2_{(f)}$ is the predictive failure test for the last five years of the sample distributed approximately as $\chi^2_{(5)}$ unless there is an intervention is included for one of the last five years, in which case it is distributed approximately as $\chi^2_{(4)}$; and
- (xi) LR test is for the restriction that σ^2_η *and* σ^2_ξ are equal to zero, distributed as $\chi^2_{(2)}$ or *either* σ^2_η *or* σ^2_ξ, is equal to zero, distributed as $\chi^2_{(1)}$.

For asymmetry, there is more variation. For nine countries, the full asymmetry with stochastic trend (FASt) model is preferred: Austria, Belgium, France, Greece, Italy, Norway, Spain, Switzerland and the UK. For two countries, the restricted asymmetry I model with a stochastic trend (RAISt) model is preferred: the Netherlands and the USA, with two countries, Japan and Portugal, the restricted asymmetry II with stochastic trend (RAIISt) model is preferred.[14]

Therefore, it can be seen that a stochastic exogenous UEDT is generally preferred with APR; nevertheless, this is not uniform across all countries. Therefore, arguably the analysis emphasises the need for any general model to allow for both APR ***and*** a non-linear exogenous

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[14] Although it should be noted that the preferred models for seven countries (Austria, Belgium, Greece, Norway, Spain, Switzerland and the UK) are observationally equivalent being possible restricted versions of both FASt and RAIISt. This is because both π^* and δ^* (the long-run p_{rec} and price p_{rec} elasticities) are found to be zero that comes about either because these are found to be zero directly in the FAS model or the long-run p_{change} elasticity (ψ^*) is found to be zero in the RAISt model.

UEDT since there could well be a role for both when modelling industrial energy demand (and arguably, any energy demand model) – however it is unlikely to be uniform across different countries (and arguably different sectors).

3.3 Discussion of results

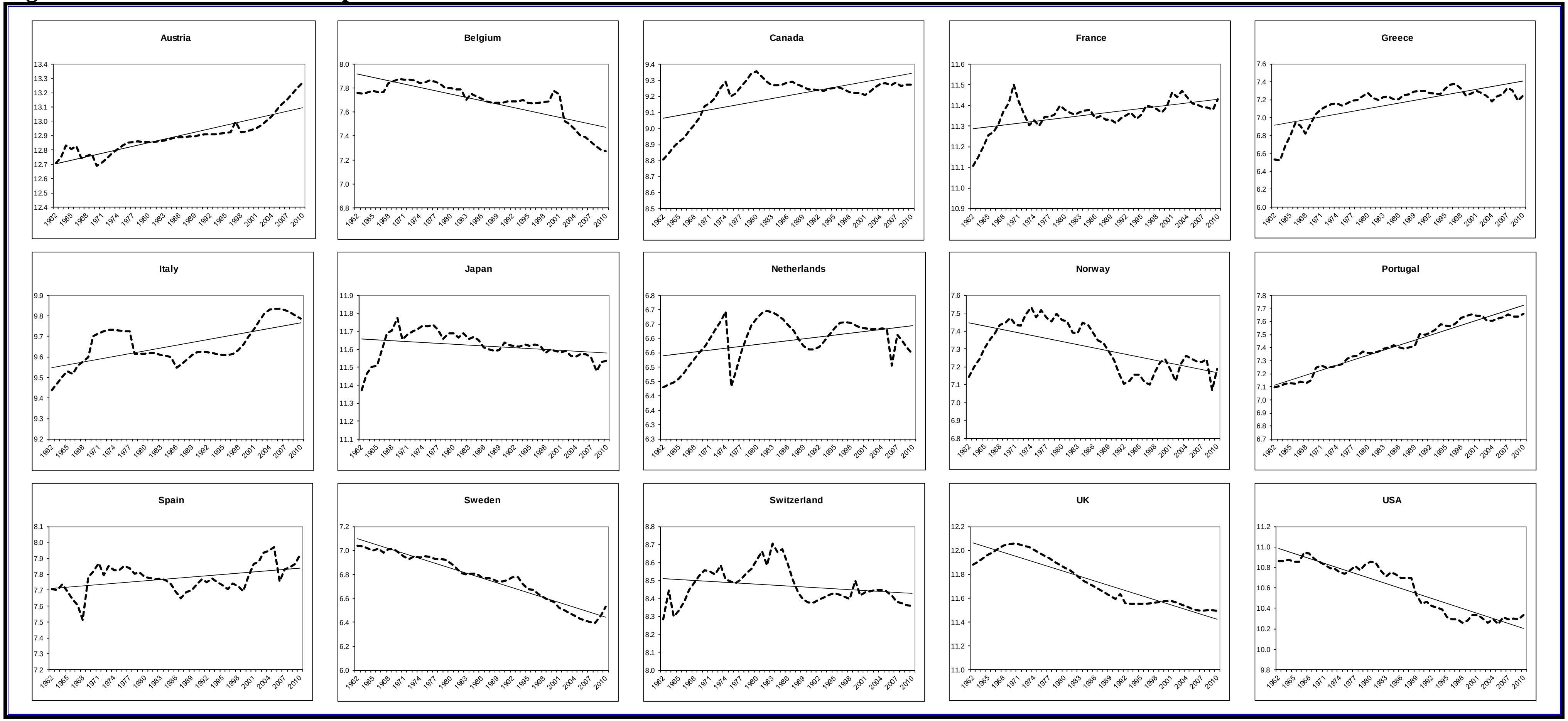
Given the complex processes involved in the industrial sector and the mounting environmental pressures and regulations as well as mandated energy efficiency standards, arguably it has never been more important to devise an appropriate methodology to account for technical progress (and other exogenous factors) in the OECD industrial sector. This paper has explored the modelling of industrial energy demand for 15 OECD countries using principles argued by Adeyemi & Hunt (2007) and the methodology advocated by Hunt et al (2003a and 2003b) but incorporating aspects advocated by Gately and Huntington (2002). The estimation was conducted using a 'general-to-specific' philosophy initially incorporating asymmetric price responses and a stochastic underlying trend. Restricted versions of this were only considered if suggested by the data. The results from this procedure show that for all bar two countries some form of asymmetry is found and that for all countries a stochastic underlying trend is found. However, there is a high degree of heterogeneity across all countries in terms of the different form of asymmetry, the different shapes of the underlying trends and the estimated income and price elasticities. It is therefore argued, consistent with Adeyemi and Hunt (2007) and Adeyemi et al. (2010), that any general model of energy demand should encompass both APR and a UEDT – thus being capable of capturing both the endogenous technical progress and exogenous influences.

Turning to the results found for OECD industrial energy demand in more detail it can be seen from Table 3 that the countries can be categorised into two groups. However, by far the dominant group is those with some form of asymmetry and a stochastic trend, the exceptions being Canada and Sweden where symmetry with a stochastic trend is found. Within this, however, there is still some variation in the estimated income and price elasticities and shapes of the estimated UEDTs (illustrated in Fig. 1). The long-run income elasticity varies from 0.34 (for Austria) to 0.96 (for Spain). The long-run $p_{\max}$ elasticity varies from -0.06 (for Norway) to -1.22 (for Austria), whereas, the long-run p_{rec} varies from zero (for Austria, Belgium, Greece, Norway, Spain, and Switzerland and the UK) to -0.71 (for Canada). The estimated long-run p_{cut} elasticities being somewhat smaller (in absolute terms) from zero (for Austria, Belgium, France, Greece, Italy, the Netherlands, Norway, Spain, Switzerland, the UK and the USA) to -0.13 (for japan). Moreover, given the implemented estimation strategy, it is found for all countries that the *a priori* expectation that in absolute terms, the $p_{\max}$ elasticity is greater than or equal to the p_{rec} elasticity which is greater than or equal to the p_{cut} elasticity (i.e. that $\left|\gamma^*\right| \geq \left|\pi^*\right| \geq \left|\delta^*\right|$) – something that is not always found in $p_{\max}$, p_{rec}, and p_{cut} decomposition models (see for example, Griffin and Schulman, 2005).

Table 3 Summary of Preferred Specifications

Countries	Asymmetry with stochastic exogenous trend	Symmetry with stochastic trend
Austria	√	
Belgium	√	
Canada		√
France	√	
Greece	√	
Italy	√	
Japan	√	
Netherlands	√	
Norway	√	
Portugal		
Spain	√	
Sweden		√
Switzerland	√	
UK	√	
USA	√	

Figure 1: Estimated UEDTs for preferred models



Note: Dotted lines represented the estimated UEDTS the solid lines are the trends of the estimated UEDTs.

In addition to the heterogeneity in the estimated elasticities, it is important to highlight the different estimated UEDT's shown in Fig. 1. This shows that even after controlling for endogenous price effects (all bar two being symmetric) there is still an important role for exogenous influences; being driven not only by exogenous technical progress, but also by other important exogenous effects. Moreover, it is clear from Fig. 1 that these exogenous effects vary from one country to other reflecting country specific effects, which appear not to be consistent across the industrial sectors of the OECD countries. Moreover, Fig. 1 shows that the estimated UEDT's do vary somewhat. For eight of the countries (Austria, Canada, France, Greece, Italy, the Netherlands, Portugal, and Spain) the general trends of the estimated UEDTs are upward slopping over the estimation period – suggesting exogenous 'energy using' behaviour. However, for the other seven countries (Belgium, Japan, Norway, Sweden, Switzerland, the UK and the USA) the general trends of the estimated UEDTs are downward slopping over the estimation period – suggesting exogenous 'energy saving' behaviour.

The results therefore illustrate that it is important to allow for the separate influence of income and APR from exogenous factors when modelling industrial energy demand where there is scope for considerable variations in the uptake of innovation and different government regulations and policies

4. Summary and Conclusion

This paper explores the way technical progress and improvements in energy efficiency are captured when modelling OECD industrial energy demand. The paper considers two potential ways to capture this effect – 'endogenously' via asymmetric price responses and/or 'exogenous' via the inclusion of a stochastic UEDT. Using the STSM framework, the general specifications allow for both APR (so that technical progress is endogenously induced by prices) and a UEDT (so that for technical progress and other factors, affect energy demand exogenously in a non-linear way). The results show that most of the preferred models for OECD industrial energy demand incorporate both a stochastic UEDT and APR

For seven of the 15 countries in the study, the estimated exogenous impact is ‘energy saving’ (suggesting that technical progress or so-called energy efficiency effects outweighed any possible ‘energy using’ effects). However, for the other eight countries this is not the case with the estimated exogenous impact being ‘energy using (suggesting that technical progress or so-called energy efficiency effects was outweighed by ‘energy using’ behaviour).

In summary, therefore, the analysis in this paper has brought together two rather separate strands of literature on modelling energy demand and shown that in general there is likely to be a role for ‘endogenous’ technical progress through prices (usually asymmetric) ***and*** ‘exogenous’ impacts from technical progress and other factors (usually in a stochastic way). Therefore, in any general model of energy demand, this should be the starting point, and only if accepted by the data should a more restricted version be considered.

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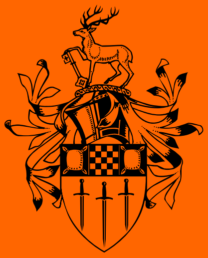

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