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OECD Energy Demand: Modelling Underlying Energy Demand Trends using the Structural Time Series Model

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ABSTRACT

Aggregate energy demand functions for 17 OECD countries are estimated with data for 1960-2003 using the Structural Time Series Model (STSM) thus allowing for a stochastic Underlying Energy Demand Trend (UEDT). It is found that the estimated long-run income and price elasticities range from 0.5 to 1.5 and -0.1 to -0.4 respectively. Furthermore the stochastic form for the UEDT is preferred for all countries suggesting a wide variation in the exogenous effects of energy saving technical progress in addition to other pertinent exogenous factors such as economic structure, consumer preferences, and socio-economic influences.

JEL Classification Numbers: O57; Q41.

Key Words: OECD Energy Demand, Modelling, Underlying Stochastic Trends.

OECD Energy Demand: Modelling Underlying Energy Demand Trends using the Structural Time Series Model*

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1. Introduction

The global concerns of climate change and the challenge to reduce CO_2 emissions and other greenhouse gases requires a detailed understanding of the factors that affect energy consumption such as income, prices, economic structure, lifestyle, climate, and energy efficiency. Reliable estimates of the key price and income elasticities are crucial tools for policy makers to help understand, explain, and predict the impact of energy and environmental policies such as carbon and energy taxes.

Given the importance of this global environmental agenda, searching for accurate and reliable values for these elasticities remains an important objective for energy economists. Never before has it been so important to estimate reliable energy demand functions with consistent and dependable price and income elasticities of energy demand in order to assist policy makers in their deliberations. Furthermore, since this is a global phenomenon these

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estimates are required for countries across the world so that comparisons can be made on a global scale using consistent data and a consistent approach – in particular for the more affluent countries such as the OECD given their relative importance in terms of energy consumption and emissions.

In the past energy economists have put a lot of time and effort into searching for the most appropriate specification of energy demand functions and the appropriate econometric techniques to estimate the key parameters of these functions. Using historical time series data they have attempted to understand the past and the present, but arguably more importantly, to also give a vision of the future. These studies have normally, but not exclusively[1], been based on time series econometric estimation of the key elasticity parameters and it is crucial that the most appropriate specification and estimation technique should be used. However, there is no unique approach for modelling energy demand and no generally accepted consensus on the correct way to proceed. Therefore, there is still some debate over the relative advantages of different econometric techniques over others and as stated by Watkins (1992) "there is no one 'technique for all seasons' " adding that it "is a matter of selecting the methodology whose strengths best match the task at hand'' (p. 29). This is an issue which is discussed in more detail below.

The rapid increase in world oil prices during the 1970s stimulated numerous energy demand studies and various surveys have shown that these are dominated by time series econometric analysis, but as Atkinson and Manning (1995) note, "there have been

[1] This paper concentrates on 'top-down' econometric and statistical analysis. This does not deny the importance of 'bottom-up' engineering type models that are seen as complements to the approach adopted here.

numerous studies on energy elasticities at the national level but rather fewer at the international level" (p. 47). Table 1 therefore presents a summary of some previous aggregate energy demand studies for OECD countries either in aggregate or multiple country studies,[2] highlighting that there have been only a few studies at this particular level with only a limited range of econometric techniques used. The majority of cited time series studies aggregated data across a number of OECD countries into a single time series to estimate average aggregate energy demand parameters; moreover the treatment of technical progress and energy efficiency (in a time series context) is sporadic at best; an issue which is discussed further below. Although the table also refers to the recent related debate (in a panel context) concerning the use of asymmetry price responses and/or time dummies to capture energy saving technical progress (Gately and Huntington, 2002; Griffin and Schulman, 2005; and Huntington, 2005).

{Table 1 about here}

The next section of the paper therefore summarises the technical progress debate and examines how energy efficiency and other non-measurable exogenous effects might be appropriately modelled. Following from this, Section 3 details the methodology and data used to estimate such models. Section 4 gives the results of the estimation followed by the final section that summarises and concludes.

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[2] As stated there have been numerous individual country studies, but Table 1 focuses on aggregate/multiple country studies for the OECD.

2. Underlying Energy Demand Trend (UEDT)

Energy demand is a derived demand; it is demanded for the services it produces in combination with the capital and appliances stock in place at any particular point of time. Therefore the changing efficiency of the capital and appliance stock is an important driver in determining energy demand hence the need to incorporate some measure or proxy for technical progress in an energy demand function; but no consensus exists on how to achieve this. In particular there has been some debate in the literature on whether or not a simple deterministic time trend is an adequate proxy for technical progress in an energy demand function in a time series context.

Observing the rise in energy productivity, Beenstock and Willcocks (1981) used a deterministic time trend as a proxy for technical progress to capture the productivity improvements, but noted that although not ideal it is an approach commonly adopted. Furthermore, they argue that ignoring the trend in energy demand functions would result in the underestimation of the long-run income elasticity. Using OECD aggregated energy data from 1950 to 1978; they found that the estimated coefficient on the linear time trend to be -0.036, indicating that autonomous technical progress occurs at 3.6% p.a., with estimated long-run price and income elasticities of -0.06 and 1.78 respectively. Whereas the exclusion of the proxy for technical progress (the linear time trend) results in estimates of -0.13 and 0.88 for the price and income elasticities respectively.

In contrast to Beenstock and Willcocks, Kouris (1983) argues strongly against including a linear time trend as an approximation for technical progress. Kouris recognised that there are a number of elements that induce technical progress in energy use such as energy policies, inter-factor substitution, fuel switching, and changes in economic structure. Furthermore, he argues that part of the technical progress is induced by price changes rather than being all autonomous. Thus according to Kouris, technical progress is caused by two elements: the price induced element and autonomous element; hence it cannot be separated from the long-run price elasticity unless there is a proper way to measure the autonomous component. Kouris (1983) therefore argues strongly against the use of a deterministic time trend stating that that "a variable … which takes the clumsy values 1, 2, 3… etc will not do the trick" (p. 207) and that "the issue of technical progress, in estimating energy demand functions, cannot really be tackled unless a satisfactory way of measuring this phenomenon can be found" (p. 210). He does accept that certain engineering data [3] could be considered as a proxy for technical progress in preference to a deterministic time trend but in the absence of these proxies "it is probably preferable … to estimate the income and price effect *without* explicitly allowing for technical progress" (p. 210, italics added). Therefore based on this approach (i.e. with no time trend), Kouris estimated, using OECD countries aggregated data from 1950 to 1970, that the long-run price and income elasticities were -0.43 and 0.70 respectively.

In their reply, Beenstock and Willcocks (1983) reject this, stating that "time trends may be poor proxies for technical progress, but for the lack of anything better this is standard practice" (p. 212). This view is supported by Welsch (1989) who also considered the issue. He estimated aggregate energy demand functions for eight OECD countries, (USA, Germany, Japan, France, the UK, Italy, Netherlands, and Canada) using data over the period 1970 to 1984, with different specifications and a set of criteria applied to the estimated models. In particular he investigates whether including a time trend is

[3] For example 'the ratio of miles per gallon over time for an average engine size' for the transport sector, 'the energy efficiency of a standard boiler' for the industrial sector and 'the energy needed to raise temperature to a given degree for a certain space' for the household sector (p. 210).

appropriate or not and concludes that a linear time trend is preferred for the UK, France, Canada and Germany, but not for the USA, Italy and the Netherlands, but the latter group have much higher estimated price elasticities (in absolute terms) and lower income elasticities than the former group. The results imply that the improvements of energy efficiency in the latter group were induced by price changes, whereas for the former group of countries, there are clear tendencies of autonomous improvement of energy efficiency that can be identified, and price elasticities are lower because the predominantly measure pure substitution effect, Welsch (1989, p. 290). Furthermore, because the pure income effect and technical progress are separated, then income elasticities may be higher in this case (p. 290). Due to the variation in the results between the countries, he suggested that energy demand should be modelled on a country by country basis rather than imposing a single model (p. 291)

Jones (1994) re-examined the way technical progress could be accounted for when estimating aggregate energy demand functions for seven OECD countries.[4] He argued that an increase in the price of energy leads to a movement along the energy demand curve (short run effect) but if the increase in the price is sustained, this motivates the energy users to replace their current equipment with more efficient stock, therefore shifting the energy curve to the left over time such that price driven technical progress has long-run effects. Jones agreed with Kouris that other non-price factors contribute to the improvement in the technical progress of energy as a response to environmental regulations, efficiency standards of the stock, substitution between factor of production and a structural shift toward less energy intensive usage. Jones (1994) goes on to argue that "reductions in

[4] Jones recognised the complication of estimating aggregate energy elasticities is the presence of technical progress, in addition to aggregation across countries and various types of energy.

aggregate energy demand due to technical progress are distinct from the standard long-run adjustments to price increases” (p. 245). Therefore, using aggregated data for OECD countries over the period 1960 to 1990, Jones found that the estimated coefficient of the linear time trend to be -0.015, implying an autonomous reduction of energy consumption in the OECD of 1.5 % p.a.; and the estimated long-run price to be -0.70 whereas Jones’ results supports the Kouris view that there is no long-run income effect.

To summarise, many researchers agree that there is an important role for of the effect of technical progress in determining the consumption of energy. Moreover, they are aware that it is not (usually) observable and therefore there is less agreement on how this effect should be incorporated when trying to estimate energy demand functions in order to avoid any bias that might be introduced if ignored. Improvements in technology take place in the economy over time but not necessarily at a fixed rate. Moreover, there are times when improvements in technology (and hence improved energy productivity) may occur very rapidly, whereas at other times it might be much slower. In other words, it is unlikely to occur at a steady continuous rate. Therefore when estimating energy demand functions it is essential that the models are flexible enough to allow for this non-deterministic pattern for technical progress or improvements in energy efficiency.

However, in addition to the important energy saving technical progress effect Hunt et al (2003a & 2003b) argue that there are a range of other exogenous factors (distinct from income and price) that potentially will have an important impact on energy demand, for example: environmental pressures and regulations; energy efficiency standards; substitution of labour, capital or raw materials for energy inputs; and general changes in tastes that could lead to a more ***or*** less energy intensive situation (such as in the UK the switch from coal to natural gas by households and the increase in the use of vehicles for taking children to school). In addition, if the analyse is at the aggregate level then the change in economic structure will also be important, such as a switch from energy intensive manufacturing to less energy intensive services.[5]

Consequently, there are a number of exogenous factors (grouped together as 'tastes' to distinguish them from energy saving technical progress) that will have an important impact on energy consumption at various times, but are unlikely to have an even and constant impact and will therefore vary over time (both positively and negatively). Hence there is a need for a broader concept to capture not only energy saving technical progress in an energy demand function but also other unobservable factors that might produce energy efficiency (or possibly inefficiency).[6] The concept of the underlying energy demand trend (UEDT)[7] is therefore used since arguably it acts as a proxy, not only for energy saving technical progress and improved energy efficiency, but also the change in the 'tastes' outlined above (Hunt et al, 2003a and 2003b).[8]

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[5] But this equally applies to 'aggregate' sectoral analysis, such as energy demand for the manufacturing sector where, for example, there is a switch from an energy intensive chemicals sector to less energy intensive electronics sector.

[6] In addition, a concept is required that, following Jones (1994), is able to capture price (and income) 'shocks' above the 'normal bounds' of price (and income) changes (Hunt, *et al.*, 2003b) possibly reflecting some asymmetry in price (and income) responses.

[7] This is similar to what is sometimes called autonomous energy efficiency improvement (AEEI) which according to Gately and Huntington (2002) is not related to energy price movements but is brought about by trends in technology, the structural mix of the economy, or other factors that have not been included. However, this assumes that there is always an *improvement* in energy efficiency (i.e. it is *energy saving*) whereas as argued above, there may be factors that result in a *deterioration* in energy efficiency (i.e. it is *energy using*) hence the term UEDT is adopted here.

[8] Hunt and Ninomiya (2003) illustrate that the UEDT for transportation oil demand in Japan and the UK is related to a combination and interaction of changes in fuel efficiency and socio-economic factors.

Given these different factors it is unreasonable to expect the UEDT to be linear; in other words, referring to Kouris (1983) again, it is unlikely that a variable which takes the clumsy values 1, 2, 3… etc will do the trick. Although the engineering data that Kouris refers to are still not readily available,[9] this argument is now redundant due to the advances in a certain technique. The Structural Time Series Model (STSM) developed by Harvey (1989 and 1997 for example) allows for the UEDT to be modelled in a stochastic fashion hence it may vary over time (both positively and negatively) if supported by the data and is therefore a particularly useful and convenient tool in these circumstances.[10] Furthermore, the more traditional formulations with a linear deterministic time trend (or maybe no trend at all) become limiting cases within this framework; hence the validity of the deterministic restrictions can be tested and only accepted if supported by the data. This UEDT/STSM approach has been applied to the UK and Japan and all conclude that it is a superior approach to one that uses a deterministic trend to try and capture technical progress and moreover the elasticity estimates and the shapes of the UEDTs are robust to different lengths and frequencies of data (Hunt et al., 2003a & 2003b; Hunt and Ninomiya, (2003); Dimitropoulos, et al., 2005). However, as far as is known this has not been applied across a number of OECD countries using a consistent data base, hence this approach is adopted here for estimating energy demand functions for the 17 OECD countries (Austria, Belgium, Canada, Denmark, France, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal,

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[9] In a time series context at least.

[10] The UEDT concept is closely related to the issue of using time dummies in a panel context to capture the effect of energy saving technical progress (Griffin and Sshulamn, 2005) since arguably the dummies capture the 'non-linear' nature of any efficiency improvement (or deterioration).

Spain, Sweden, Switzerland, the UK and the US). Exact details of the methodology are given in the next section with the results given in the subsequent section.

3. Modelling Procedure

Methodology

The above discussion focussed on the conceptual issue of modelling technical progress using a deterministic trend and hence the arguments for using the alternative STSM estimating technique. However, there are also strong statistical arguments for using this technique as opposed to the more generally accepted technique of unit roots and cointegration. Harvey (1997) heavily criticises the over reliance on the cointegration methodology as being unnecessary and/or a misleading procedure due, to amongst other things, its poor statistical properties, concluding the paper by stating that the "recent emphasis on unit roots, vector autoregressions and co-integration has focussed too much attention on tackling uninteresting problems by flawed methods" (p. 200). He proposes instead, "to combine the flexibility of a time series model with the interpretations of regression" and argues that this is "exactly what is done in the structural time series approach" (p. 200).

Given all these arguments an Autoregressive Distributed Lag (ADL) log linear model[11] with a stochastic trend is used to estimate the energy demand functions for the 17 OECD countries as follows:

$$A(L)e_t = \mu_t + B(L)y_t + C(L)p_t + \varepsilon_t \qquad \textbf{(1)}$$

[11] The log-linear model is employed given its simplicity and easy interpretation; moreover, Pesaran et al. (1998) argue that it generally outperforms more complex specifications.

Where e_t, y_t, and p_t are aggregate energy consumption, GDP and the real energy price (all in natural logarithms), $A(L)$ is the polynomial lag operator $L - \phi_1 L - \phi_2 L^2 - \ldots - \phi_p L^p$, $B(L)$ is the polynomial lag operator $\delta_0 + \delta_1 L + \delta_2 L^2 + \ldots + \delta_p L^p$ and $C(L)$ is the polynomial lag operator $\pi_0 + \pi_1 L + \pi_2 L^2 + \ldots + \pi_p L^p$. $B(L)/A(L)$ and $C(L)/A(L)$ represent the long-run income and price elasticities, respectively.

The trend component μ_t is assumed to have the following stochastic process:

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

$$\beta_t = \beta_{t-1} + \xi t \qquad \zeta_t \sim NID(0,\sigma_\zeta^2) \qquad \textbf{(3)}$$

Where equations (2) and (3) represent the level and the slope respectively, with the shape of the underlying trend dependent upon the variances σ_η^2 and σ_ζ^2 (also known as the hyperparameters); the larger the hyperparameters the greater the stochastic movements in the trend. In the limiting case when the hyperparameters are equal to zero the model collapses to a conventional deterministic time trend regression. This therefore gives a number of alternative forms of the stochastic trend depending on the values of the hyperparameters.[12]

The initial general model to be estimated therefore consists of equation (1) with (2) and (3) with the lag operator, L, equal to four. All disturbance terms are assumed to be independent and uncorrelated with each other. The estimation is carried out by maximum likelihood and the hyperparameters are obtained from a smoothing algorithm using the Kalman filter. For model selection, equation residuals are estimated (similar to those from

[12] A classification of the different types is given in Table 9.2 in Hunt et al (2003b)

ordinary regression), in addition to a set of auxiliary residuals (irregular, level and slope).[13] The final preferred specification for each individual country is found by testing down from the initial general model provided that the equation passes an array of diagnostic tests which are described in more detail in the results section below.[14] In addition, a Likelihood Ratio (LR) test is undertaken to test the restriction of a deterministic trend against the estimated stochastic trend. The software package STAMP 6.3 (Koopman et al, 2000) is used for all estimation.

Data

The data set covers the period 1960-2003 for 17 OECD countries: Austria, Belgium, Canada, Denmark, France, Greece, Ireland, Italy, Japan, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, the UK, and the US.[15] The primary source of these data is the International Energy Agency (IEA) database *Energy Statistics of OECD Countries* available at www.iea.org.[16] This includes each country's aggregate energy consumption (E) in thousand tonnes of oil equivalent (ktoe) and economic activity (Y) defined as GDP in constant US$ at 2000 prices over the whole period 1960-2003 and are illustrated in Figure1 and Figure 2 respectively. Figure 1, shows that in general most countries energy consumption follows a general upward trend although with different short-run fluctuations

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[13] Of course, level and slope residuals are only estimated if the associated trend components are non-zero

[14] Following Harvey and Koopman (1992), this includes testing and examination of the auxiliary residuals to identify outliers and structural breaks and, if necessary, appropriate dummies incorporated in the models.

[15] Germany is omitted given the problems of obtaining a consistent data set over the whole period due to re-unification. Other OECD countries were omitted given it was not possible to obtain a real price series back to 1960.

[16] The 2005 version.

and growth rates. Similarly, Figure 2 shows that the GDP for each country generally follow similar overall trends.

{Figure 1 about here}

{Figure 2 about here}

The index of real energy prices (2000=100) is also taken from the IEA database, but is only for the period 1978 – 2003. 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.[17] 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 – 2003; 2000=100) are subsequently spliced using the ratio from the overlap year 1978 to obtain the real energy price index (P) for each country over the whole period 1960 to 2003 at 2000 prices (2000=100). These data are illustrated in Figure 3 and shows that for all countries the aggregate real energy price has been affected by the world oil price shocks, but within these overall trends there are some differences due to factors such as local taxes, etc.

{Figure 3 about here}

Finally, energy intensity (derived from the above data as the ratio of total energy consumption, E to GDP, Y) warrants some consideration given it reflects such factors as a country's economic structure, fuel mix and level of technology (Sun, 2002) and to a large

[17] This source was used in a similar way by Prosser (1985).

part is determined by the income elasticity, but it is also related to other factors such as the price elasticity, induced technical change and exogenous factors such as changing consumer preferences for less (or more) energy intensive products, the emergence of new improved materials, changing economic structure, and exogenous changes in technology that reduces the energy embodied in finished goods. All of which is pertinent to the approach taken here to estimate a stochastic underlying energy demand trend which is outlined above. It is informative, therefore, before undertaking the estimation to consider the development of energy intensity over the estimation period; hence Figure 4 gives energy intensity (indexed to 1970 = 100) for the 17 countries in the data set. This shows that for most countries energy intensity was less at the end of the period than at the beginning, the exceptions being Greece, Italy, the Netherlands, Portugal, Spain, and Switzerland. Moreover, most of the improvements in energy intensity have arisen since the time of the first oil price shock of the early 1970s; which, for many, brought about a reversal in an upward trend. Hence for most countries (which for convenience will be classed as *Group A*) energy intensity fell on average over the period 1973 to 2000: Austria (-1.1% p.a.), Belgium (-1.5% p.a.), Canada (-1.6% p.a.), Denmark (-2.0% p.a.), France (-1.7% p.a.), Ireland (-2.3% p.a.), Italy (-1.2% p.a.), Japan (-1.3% p.a.), Netherlands (-1.8% p.a.), Norway (-2.1% p.a.), Sweden (-2.0% p.a.), Switzerland (-0.6% p.a.), UK (-1.8% p.a.), and USA (-2.4% p. a.). However, for the remainder (*Group B*) energy intensity increased over the period 1973 to 2000 on average: Greece (0.9% p.a.), Portugal (1.5% p.a.), and Spain (0.3% p.a.). These groupings will be considered again later when considering the estimated UEDTs in the following section.

{Figure 4 about here}

4. Results

The aggregate energy demand functions for the 17 OECD countries were estimated over the period 1964-2000 with three observations 2001-2003 saved for post sample prediction tests and the preferred specifications for each country are presented in Table 2. This shows that the preferred models generally fit the data well with almost all diagnostic tests passed, the exceptions being:[18] the post failure prediction tests for Austria, Canada, and France at the 10%, 5% and 10% levels respectively; the Box-Ljung serial correlation test[19] for Italy which is failed at the 10% level; and one of the normality tests for the level residuals for Sweden which is failed at the 10% level. Furthermore, without exception, the restriction of a deterministic trend by restricting the hyper-parameters σ_η^2 and/or σ_ζ^2 to be zero are rejected for each country at the 1% level of significance – supporting the UEDT/STSM approach.[20]

{Table 2 about here}

Space precludes a detailed discussion of the results for the individual countries; instead the following focuses on the general results and main themes. The dynamic structure of the preferred equations varies across the countries, with some countries (such as Austria,

[18] An explanation of all diagnostic tests are given below Table 1.

[19] It should be noted that the Box-Ljung statistic (and the DW statistic) is not applicable in the presence of a lagged dependent variable and hence passing the test with a lagged dependent variable does not guarantee that there is not a problem.

[20] Although these tests are important, arguably they are conditional on the preferred model (found from the general model within the STSM framework) being the correct model for other cases. Therefore, any conclusion that the restrictions on the hyper-parameters are rejected may not necessarily be valid. Hence early preliminary work also estimated models with a deterministic trend using cointegration and found that the STSM were superior.

Denmark, Italy, Netherlands, Norway, Spain, Switzerland, and the USA) displaying adjustment within one year whereas the remainder display various degree of dynamic behaviour. Furthermore, as illustrated in Figure 5, the estimated UEDT's vary in shape across all the countries. Despite this the estimated long-run elasticities are within a relatively small range: 0.5 to 1.5 for the income elasticities and -0.1 to -0.4 for the price elasticities. Thus all estimated elasticities are within acceptable ranges and, as far as is known, in line with previous studies.[21]

{Figure 5 about here}

The range of the estimated elasticities for *Group A* and *Group B* (as identified above) for the estimated long-run income elasticities are 0.6 to 1.5 and 0.5 to 1.2 respectively; and for the estimated long-run price elasticities -0.1 to -0.4 and -0.1 to -0.3 respectively. Therefore the range of estimated price and income elasticities are fairly similar despite the different profile for energy intensity since the early 1970s. This suggests that different historical profiles of energy intensity (displayed in Figure 4) are not in general explained by the effect of changes in prices and income and hence must be explained by other (exogenous) factors. In other words the generally falling energy intensities for *Group A* countries should be associated, *ceteris paribus*, with an inward shift in the energy demand curve captured by a falling UEDT; whereas the generally rising energy intensities for *Group B* countries should

[21] For example Hunt et al (2003a) and Dimitropoulos et al (2005) both found a similar shape for the estimated UEDT for the UK economy using quarterly and annual data respectively; furthermore their estimated long-run income and price elasticities are also close to those in this study despite the different data source, different frequency of data and different length of data. Also for Denmark Bentzen and Engsted (1993) find that the estimated long-run income elasticity is slightly lower and the estimated long-run price elasticity is slightly higher (in absolute terms) than those obtained here, but given that they ignored any AEEI or UEDT effects this is not surprising.

be associated, *ceteris paribus*, with an outward shift in the energy demand curve captured by a rising UEDT. This is clearly the case for the two *Group B* countries Greece and Portugal (where energy intensity increases very rapidly) who display very steep estimated UEDTs as illustrated in Figure 5, however for Spain (where energy intensity increases but less rapid than the other *Group B* countries) the estimated UEDT is not generally rising over the whole period but has been increasing a little since the late 1980s, partly explained by Spain's larger estimated long-run income elasticity than the other two Group B countries. For the *Group A* countries most of the estimated UEDTs are generally falling since the early 1970s except for Ireland, Italy, and Switzerland where the estimated UEDT tends to 'flatten out' since the mid 1980s.

In summary, the estimated equations are generally well specified with a reasonable range of income and price elasticities. However, the estimated UEDTs are all clearly non-linear suggesting that imposing a deterministic trend would lead to biased estimates of the price and income elasticities. Hence the STSM is preferred rather than the more restrictive approach with a deterministic time trend. Moreover despite the relatively narrow range of estimated long-run elasticities the estimated UEDTs show considerable variation across the different countries, reflecting the different rates of technical progress and different institutional, cultural, and socio-economic influences across the countries.

5. Summary and Conclusion

This paper has explored the estimation of aggregate energy demand functions for 17 OECD countries focussing on the estimation of the underlying trends by adopting the STSM approach to allow for the estimation of a stochastic trend (UEDT); thus embracing unobservable influences such as energy saving technical progress and changes in consumer preferences, economic structure, socio-economic variables, etc. This gives estimated long-run income elasticities ranging from 0.5 to 1.5 and estimated long-run price elasticities ranging from -0.1 to -0.4 (across the 17 countries).

However, the estimated UEDTs vary considerably across the 17 countries in the study; reflecting, not only the different rates of technical progress and energy efficiency but also a range of other possible factors such as cultural and socio-economic changes. This illustrates the need for the flexible approach allowed by the STSM rather than more restrictive models that employ a deterministic trend in order to fully understand the development of energy intensity and also to obtain reliable estimates of the long-run income and price elasticities.

Critics of the approach taken here might argue that the stochastic UEDTs, in addition to energy saving technical change and other exogenous factors, might also be picking up asymmetric effects which are explored by, amongst others, Gately and Huntington (2002), Griffen and Shulman (2005) and Huntington (2006) in a panel context. Future work will therefore attempt to model this by incorporating asymmetric price (and possibly income) effects *and* a stochastic UEDT to test whether there is a role for one or both approaches when modelling energy demand in a time series context.[22]

[22] Effectively attempting to test whether the two approaches are substitutes or complements – paralleling the debate summarised by Huntington (2006) in a panel context.

References

Atkinson, J.and Manning, N., 1995 A Survey of International Energy Elasticities, Chapter 3 in Barker, T., Ekins, P. and Johnstone, N. (eds) *Global Warming and Energy Demand*, London, UK: Routledge, 47-105.

Baade, P., 1981.International Energy Evaluation System: International Energy Prices: 1955-1980, *Information Administration, US Department of Energy Report, SR/STID/81-21*, Washington, DC, December.

Beenstock, M. and Willcocks,P., 1981. Energy Consumption and Economic Activity in Industrialised Countries, *Energy Economics* 3, 225-232.

Beenstock, M. and Willcocks, P., 1983. Energy and Economic Activity: A Reply to Kouris, *Energy Economics* 5, 212-212.

Bentzen, J. and Engsted, T., 1993. Short- and Long-run Elasticities in Energy Demand: A Cointegration Approach, *Energy Economics* 15, 9-16.

Dimitropoulos, J., Hunt, L. C. and Judge, G, 2005. Estimating Underlying Energy Demand Trends using UK Annual Data, *Applied Economics Letters* 12, 239-244.

Gately, D. and Huntington, H. G. 2002. The Asymmetric Effects of Changes in Price and Income on Energy and Oil Demand, *Energy Journal* 23, 19-55.

Griffin, J. M. and Schulman, C. T., 2005. Price Asymmetry in Energy Demand Models: A Proxy for Energy-Saving Technical Change?, *Energy Journal* 26, 1-21.

Harvey, A. C., 1989. *Forecasting, Structural Time Series Models and the Kalman Filter*, Cambridge, UK: Cambridge University Press.

Harvey, A. C., 1997. Trends, Cycles and Autoregressions, *Economic Journal* 107, 192-201.

Harvey, A. C. and Koopman, S. J., 1992. Diagnostic Checking of Unobserved-Components Time Series Models, *Journal of Business and Economic Statistics*, 10, 377-389.

Hunt, L. C., Judge, G. and Ninomiya, Y., 2003a. Underlying Trends and Seasonality in UK Energy Demand: A Sectoral Analysis, *Energy Economics* 25, 93-118.

Hunt, L. C., Judge, G. and Ninomiya, Y., 2003b. Modelling Underlying Energy Demand Trends, Chapter 9 in Hunt, L. C. (Ed) *Energy in a Competitive Market: Essays in Honour of Colin Robinson*, Cheltenham, UK: Edward Elgar, 140-174.

Hunt, L. C. and Ninomiya, Y., 2003. Unravelling Trends and Seasonality: A Structural Time Series Analysis of Transport Oil Demand in the UK and Japan, *The Energy Journal* 24, 63-96.

Huntington, H. G., 2006. A Note on Price Asymmetry as Induced Technical Change, *Energy Journal* 27, 1-7.

Jones, C. T., 1994. Accounting for Technical Progress in Aggregate Energy Demand, *Energy Economics* 16, 245-252.

Koopman, S. J., Harvey, A. C., Doornik, J. A. and Shephard, N., 2000. *Stamp: Structural Time Series Analyser, Modeller and Predictor*, London: Timberlake Consultants Press.

Kouris, G., 1983. Fuel Consumption and Economic Activity in Industrialised Economies: A Note, *Energy Economics* 5, 207-212.

Pesaran, M. H., Smith, R. P. and Akiyama, T., 1998. *Energy Demand in Asian Developing Economies*, Oxford University Press, Oxford, UK.

Prosser, R. D., 1985. Demand Elasticities in OECD: Dynamic Aspects, *Energy Economics* 7, 9-12.

Sun, J. W., 2002. The Decrease in the Difference of Energy Intensities between OECD Countries from 1971 to 1998, *Energy Policy* 30, 631-635.

Watkins, C. C., 1982. The Economic Analysis of Energy Demand: Perspectives of a Practitioner, Chapter 2 in Hawdon, D. (Ed) *Energy Demand: Evidence and Expectations*, London, UK: Academic Press Ltd., 29-96.

Welsch, H., 1989. The Reliability of Aggregate Demand Functions: An Application of Statistical Specification Error Tests, *Energy Economics* 11, 285-292.

Table 1: Selected OECD Energy Demand Studies

Author(s)	Sector analysed	Model used and technique	Data	Estimated LR elasticities	Treatment of trend	Notes
Beenstock and Willcocks (1981)	Aggregate energy	Log linear ECM (aggregate time series model)	OECD annual data 1950 -1970	η_y = 1.78 η_p = -0.06	T= -0.038	Commercial energy consumption results show slightly smaller absolute values; this suggests that the aggregation affects the estimates. An attempt to restrict income elasticity to unity is rejected.
Kouris (1983b)	Aggregate primary energy	Dynamic log linear reduced form (aggregate time series model)	OECD annual data 1961-81	η_y = 0 (restricted) η_p = -0.43	Not included	Overlapping 13 years period results are presented
Prosser (1985)	Aggregate energy	Dynamic log linear reduced form with different specifications (aggregate time series model)	OECD annual data 1960-82	η_y = 1.02 η_p = -0.40	Not included	Specifies one static model and 4 dynamic models; Koyck model is preferred.
Welsch (1989)	Aggregate energy	Dynamic log linear model with various specifications (aggregate time series model)	Annual data for 8 OECD countries 1970-1984	η_y = 0.70 – 2.30 η_p = -0.10 - -0.90	T=included in general but results not reported (but accepted for	The rejection of the time trend for some countries implied that improvements of energy efficiency are price induced. Also estimated pooled model but rejected in favour of individual country models.

Jones (1994)	Aggregate energy	ARDL (aggregate time series model)	OECD annual data 1960-90	$\eta_y = 0$ $\eta_p = -0.70$	T = -0.015	Long-run income elasticity not estimated in preferred model.
Gately and Huntington (2002)	Aggregate energy	Log linear asymmetric price (and income) Koyck lag model (panel)	OECD and non-OECD annual panel data 1971 – 1996	$\eta_y = 0.59$ $\eta_p = -0.24$	Not included – implicitly assumed all induced	Also estimated oil demand functions.
Grifin and Schulman (2005)	Aggregate energy	Log linear asymmetric price Koyck lag model (panel)	OECD and annual panel data 1961 – 1996	$\eta_y = 0.41$ $\eta_p = -0.04$	Time dummies with trend that decreases over time	Also estimated oil demand functions

η_y and η_p are the estimated long run income and price elasticities respectively.
T is the estimated coefficient for the deterministic time trend.

Table 2: The Estimated Results for Aggregate Energy Demand Using the STSM

	Austria	Belgium	Canada
Parameter Estimates			
y_t	0.74**	1.13***	
y_{t-1}			0.99***
Δy_t			0.59***
p_t	-0.17**	-0.25***	
p_{t-1}		-0.12**	
p_{t-4}			-0.12**
Δe_{t-3}		0.19*	
Long-Run Elasticity Estimates			
Income (Y)	0.74	1.13	0.99
Price (P)	-0.17	-0.25	-0.12
Estimated Hyperparameters			
Irregular standard deviation	0.0050	0.0000	0.0000
Level standard deviation	0.0285	0.0349	0.0189
Slope standard deviation	0.0007	0.0000	0.0044
Trend			
Form of UEDT	Local	Local level with drift (with Irr1996)	Local (with Irr1975 &Irr1998)
Growth rate at end of period	-0.07% p.a.	-0.93% p.a.	-2.00% p.a.
Diagnostics			
Equation residuals			
Standard error	2.81%	3.20%	1.91%
Normality	1.90/2.56	1.23/1.16	1.30/1.28
Kurtosis	0.05	0.98	1.08
Skewness	1.85	0.25	0.22
Heteroscedasticity	$H_{(11)}$ = 4.78	$H_{(11)}$ = 0.58	$H_{(11)}$ = 1.04
$r_{(1)}$	-0.06	0.26	0.18
$r_{(2)}$	-0.20	-0.11	-0.02
$r_{(3)}$	0.10	-0.21	-0.15
DW	2.07	1.37	1.61
Box-Ljung statistic	$Q_{(10,7)}$ = 5.33	$Q_{(10,8)}$ = 11.20	$Q_{(10,7)}$ = 7.30
R^2	0.98	0.97	0.99
Auxiliary residuals			
Irregular			
Normality	0.25/0.06	0.85/0.44	0.24/0.57
Kurtosis	0.06	0.76	0.02
Skewness	0.00	0.09	0.22
Level			
Normality	1.95/1.55	0.89/0.52	1.24/1.46
Kurtosis	0.07	0.76	0.29
Skewness	1.48	0.13	0.95
Slope			
Normality	0.93/0.71	n/a	1.19/1.30
Kurtosis	0.62	n/a	0.52
Skewness	0.31	n/a	0.67
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	**7.41***	3.90	**9.64****
Likelihood Ratio Tests			
LR	$\chi^2_{(2)}$ = 9.97***	$\chi^2_{(1)}$ = 38.15***	$\chi^2_{(2)}$ = 32.63***

Table 2 continued

	Denmark	France	Greece
Parameter Estimates			
y_t	1.48***	0.86**	0.90***
p_t	-0.14*	-0.26***	
p_{t-1}			-0.27***
Δp_t			-0.13**
e_{t-1}		0.41***	
Δe_{t-2}		0.13	
Long-Run Elasticity Estimates			
Income (Y)	1.48	1.45	0.90
Price (P)	-0.14	-0.44	-0.27
Estimated Hyperparameters			
Irregular standard deviation	0.0083	0.0000	0.0177
Level standard deviation	0.0333	0.0259	0.0002
Slope standard deviation	0.0042	0.0000	0.0034
Trend			
Form of UEDT	Local (with Irr974 & Irr1982)	Local level with drift (with Irr1970 & Irr1991)	Local (with Lvl1970)
Growth rate at end of period	-2.89% p.a.	-1.23% p.a.	-0.30% p.a.
Diagnostics			
Equation residuals			
Standard error	3.43%	2.30%	2.21%
Normality	0.85/0.70	0.66/0.66	0.24/0.69
Kurtosis	0.43	0.15	0.01
Skewness	0.42	0.51	0.23
Heteroscedasticity	$H_{(11)} = 1.25$	$H_{(11)} = 0.73$	$H_{(11)} = 1.09$
$r_{(1)}$	-0.07	-0.00	-0.05
$r_{(2)}$	0.09	0.05	-0.19
$r_{(3)}$	-0.29	-0.19	-0.02
DW	1.99	1.99	1.84
Box-Ljung statistic	$Q_{(10,7)} = 7.83$	$Q_{(10,8)} = 11.80$	$Q_{(10,7)} = 3.37$
R^2	0.90	0.99	0.99
Auxiliary residuals			
Irregular			
Normality	1.51/1.91	1.38/1.65	1.92/2.98
Kurtosis	0.09	0.72	1.33
Skewness	1.42	0.66	0.60
Level			
Normality	1.20/0.89	0.01/0.56	0.12/0.52
Kurtosis	0.01	0.01	0.02
Skewness	1.89	0.00	0.10
Slope			
Normality	0.52/0.31	n/a	0.25/0.03
Kurtosis	0.29	n/a	0.25
Skewness	0.23	n/a	0.01
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	1.19	**6.28***	0.81
Likelihood Ratio Tests			
LR	$\chi^2_{(2)} = 25.86$***	$\chi^2_{(1)} = 11.43$***	$\chi^2_{(2)} = 24.53$***

Table 2 continued

	Ireland	Italy	Japan
Parameter Estimates			
y_t		0.79***	0.78***
y_{t-2}	0.64**		
Δy_{t-3}	-0.54**		
p_t		-0.15***	
p_{t-1}	-0.19**		-0.19***
Long-Run Elasticity Estimates			
Income (Y)	0.64	0.79	0.78
Price (P)	-0.19	-0.15	-0.19
Estimated Hyperparameters			
Irregular standard deviation	0.0074	0.0070	0.0105
Level standard deviation	0.0395	0.0117	0.0133
Slope standard deviation	0.0011	0.0085	0.0079
Trend			
Form of UEDT	Local	Local	Local (with Lvl1980)
Growth rate at end of period	0.34% p.a.	-0.07% p.a.	0.01% p.a.
Diagnostics			
Equation residuals			
Standard error	3.86%	1.95%	2.29%
Normality	1.02/0.65	0.84/0.50	1.26/2.27
Kurtosis	0.96	0.67	0.23
Skewness	0.06	0.17	1.02
Heteroscedasticity	$H_{(11)}$ = 0.54	$H_{(11)}$ = 0.75	$H_{(11)}$ = 0.34
$r_{(1)}$	-0.03	-0.03	-0.04
$r_{(2)}$	0.10	-0.16	-0.01
$r_{(3)}$	-0.09	0.01	-0.06
DW	1.95	1.95	1.96
Box-Ljung statistic	$Q_{(10,7)}$ = 10.72	**$Q_{(10,7)}$ = 13.99***	$Q_{(10,7)}$ = 4.90
R^2	0.98	0.99	0.99
Auxiliary residuals			
Irregular			
Normality	2.42/1.74	0.46/0.75	0.73/0.89
Kurtosis	0.26	0.02	0.05
Skewness	1.48	0.44	0.68
Level			
Normality	0.55/0.11	1.19/1.32	0.48/0.75
Kurtosis	0.51	0.48	0.02
Skewness	0.04	0.71	0.46
Slope			
Normality	0.77/0.37	0.13/0.56	0.74/0.72
Kurtosis	0.66	0.01	0.18
Skewness	0.11	0.12	0.56
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	3.55	4.42	3.38
Likelihood Ratio Tests			
LR	$\chi^2_{(2)}$ = 36.66***	$\chi^2_{(2)}$ = 64.35***	$\chi^2_{(2)}$ = 44.43***

Table 2 continued

	Netherlands	Norway	Portugal
Parameter Estimates			
y_t	1.42***	0.59**	
y_{t-1}			0.49***
Δy_t			0.29**
p_t	-0.17*	-0.19**	-0.13**
Δp_{t-3}			-0.08**
Long-Run Elasticity Estimates			
Income (Y)	1.42	0.59	0.49
Price (P)	-0.17	-0.19	-0.13
Estimated Hyperparameters			
Irregular standard deviation	0.0152	0.0170	0.0047
Level standard deviation	0.0351	0.0000	0.0219
Slope standard deviation	0.0067	0.0119	0.0000
Trend			
Form of UEDT	Local	Smooth	Local level with drift
Growth rate at end of period	-2.90% p.a.	-1.66% p.a.	2.90% p.a.
Diagnostics			
Equation residuals			
Standard error	4.22%	2.94%	2.10%
Normality	0.03/0.42	0.58/0.09	0.94/0.49
Kurtosis	0.03	0.58	0.94
Skewness	0.00	0.00	0.00
Heteroscedasticity	$H_{(11)} = 0.71$	$H_{(11)} = 0.54$	$H_{(11)} = 1.06$
$r_{(1)}$	-0.06	0.02	-0.02
$r_{(2)}$	-0.16	-0.16	-0.11
$r_{(3)}$	0.10	-0.12	-0.15
DW	2.03	1.86	2.01
Box-Ljung statistic	$Q_{(10,7)} = 5.80$	$Q_{(10,8)} = 8.07$	$Q_{(10,8)} = 9.39$
R^2	0.98	0.98	0.99
Auxiliary residuals			
Irregular			
Normality	1.62/2.16	1.18/1.67	0.05/0.32
Kurtosis	1.05	0.03	0.05
Skewness	0.57	1.15	0.01
Level			
Normality	0.67/1.18	n/a	0.26/0.16
Kurtosis	0.00	n/a	0.17
Skewness	0.67	n/a	0.09
Slope			
Normality	0.95/0.85	0.13/0.81	n/a
Kurtosis	0.48	0.00	n/a
Skewness	0.47	0.13	n/a
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	2.87	4.15	3.16
Likelihood Ratio Tests			
LR	$\chi^2_{(2)} = 45.36$***	$\chi^2_{(2)} = 54.89$***	$\chi^2_{(1)} = 14.71$***

Table 2 continued

	Sweden	Spain	Switzerland
Parameter Estimates			
y_t		1.22***	0.74***
y_{t-1}	0.60**		
p_t	-0.25***	-0.09*	-0.25***
Long-Run Elasticity Estimates			
Income (Y)	0.60	1.22	0.74
Price (P)	-0.25	-0.09	-0.25
Estimated Hyperparameters			
Irregular standard deviation	0.0000	0.0000	0.0096
Level standard deviation	0.0300	0.0295	0.0279
Slope standard deviation	0.0039	0.0015	0.0042
Trend			
Form of UEDT	Local	Local	Local
Growth rate at end of period	-0.57% p.a.	0.14% p.a.	-0.14% p.a.
Diagnostics			
Equation residuals			
Standard error	3.02%	2.85%	3.15%
Normality	1.89/3.07	1.61/1.99	0.81/0.84
Kurtosis	1.10	0.00	0.16
Skewness	0.79	1.61	0.64
Heteroscedasticity	$H_{(11)} = 0.59$	$H_{(11)} = 0.17$	$H_{(11)} = 0.50$
$r_{(1)}$	-0.00	0.02	-0.08
$r_{(2)}$	-0.05	-0.07	-0.04
$r_{(3)}$	0.03	0.22	-0.18
DW	1.94	1.86	2.06
Box-Ljung statistic	$Q_{(10,7)} = 1.87$	$Q_{(10,7)} = 6.15$	$Q_{(10,7)} = 11.37$
R^2	0.91	0.99	0.97
Auxiliary residuals			
Irregular			
Normality	0.51/0.66	0.35/2.26	1.76/2.70
Kurtosis	0.06	0.24	0.47
Skewness	0.46	0.11	1.29
Level			
Normality	0.24/**4.89***	1.06/1.26	1.88/2.49
Kurtosis	0.67	0.06	0.05
Skewness	1.82	1.00	1.83
Slope			
Normality	1.42/1.52	0.34/0.01	1.84/2.29
Kurtosis	1.15	0.34	1.82
Skewness	0.27	0.01	0.02
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	0.25	0.95	2.23
Likelihood Ratio Tests			
LR	$\chi^2_{(2)} = 45.81$***	$\chi^2_{(2)} = 28.74$***	$\chi^2_{(2)} = 32.45$***

Table 2 continued

	UK	USA
Parameter Estimates		
y_t	0.81***	0.81***
p_{t-1}		-0.10*
$p_t - p_{t-2} + p_{t-3}$	-0.07**	
Long-Run Elasticity Estimates		
Income (Y)	0.81	0.81
Price (P)	-0.07	-0.10
Estimated Hyperparameters		
Irregular standard deviation	0.0000	0.0000
Level standard deviation	0.0142	0.0186
Slope standard deviation	0.0000	0.0051
Trend		
Form of UEDT	Local level with drift (with Irr1979, Irr1996, & Lvl1991)	Local
Growth rate at end of period	-1.21% p.a.	-1.05% p.a.
Diagnostics		
Equation residuals		
Standard error	1.28%	2.02%
Normality	1.85/2.58	0.79/0.30
Kurtosis	0.11	0.79
Skewness	1.74	0.00
Heteroscedasticity	$H_{(11)}$ = 0.56	$H_{(11)}$ = 0.70
$r_{(1)}$	-0.08	0.05
$r_{(2)}$	-0.21	-0.16
$r_{(3)}$	-0.16	0.08
DW	1.48	1.82
Box-Ljung statistic	$Q_{(10,8)}$ = 8.38	$Q_{(10,7)}$ = 6.04
R^2	0.97	0.97
Auxiliary residuals		
Irregular		
Normality	0.49/0.20	0.78/0.97
Kurtosis	0.35	0.04
Skewness	0.14	0.74
Level		
Normality	1.60/2.14	0.38/0.11
Kurtosis	0.22	0.29
Skewness	1.38	0.09
Slope		
Normality	n/a	1.99/2.67
Kurtosis	n/a	1.98
Skewness	n/a	0.01
Post Sample Predictive tests (1999 – 2000)		
Failure $\chi^2_{(3)}$	4.92	0.25
Likelihood Ratio Tests		
LR	$\chi^2_{(1)}$ = 38.90***	$\chi^2_{(2)}$ = 75.60***

Notes for Table 2

- *** indicates significant at 1% level, ** indicates significant at the 5% level and * indicates significant at the 10% level.
- Normality is tested via the Bowman-Shenton and Doornik-Hansen statistics; both approximately distributed as $\chi^2_{(2)}$.
- Kurtosis statistic is approximately distributed as $\chi^2_{(1)}$.
- Skewness statistic is approximately distributed as $\chi^2_{(1)}$.
- $H_{(h)}$ is the test for heteroscedasticity, distributed approximately as $F_{(h,h)}$.
- $r_{(\tau)}$ the residual autocorrelation at lag τ distributed approximately as $N(0, 1/T)$.
- DW-Durbin-Watson statistic.
- $Q_{(p,d)}$ is the Box-Ljung statistic based on the first p residuals autocorrelations and distributed approximately as $\chi^2_{(d)}$.
- R^2 is the coefficient of determination,
- Failure $\chi^2_{(3)}$ is the post-sample predictive failure test for the three year period 2001 to 2003.
- LR test for restricting the stochastic trend hyper-parameters (r) to be zero, approximately distributed as $\chi^2_{(r)}$.
- *Irr*, *Lvl* and *Slp* represent Irregular, Level and Slope interventions respectively.

Figure 1 Energy Consumption (mtoe)

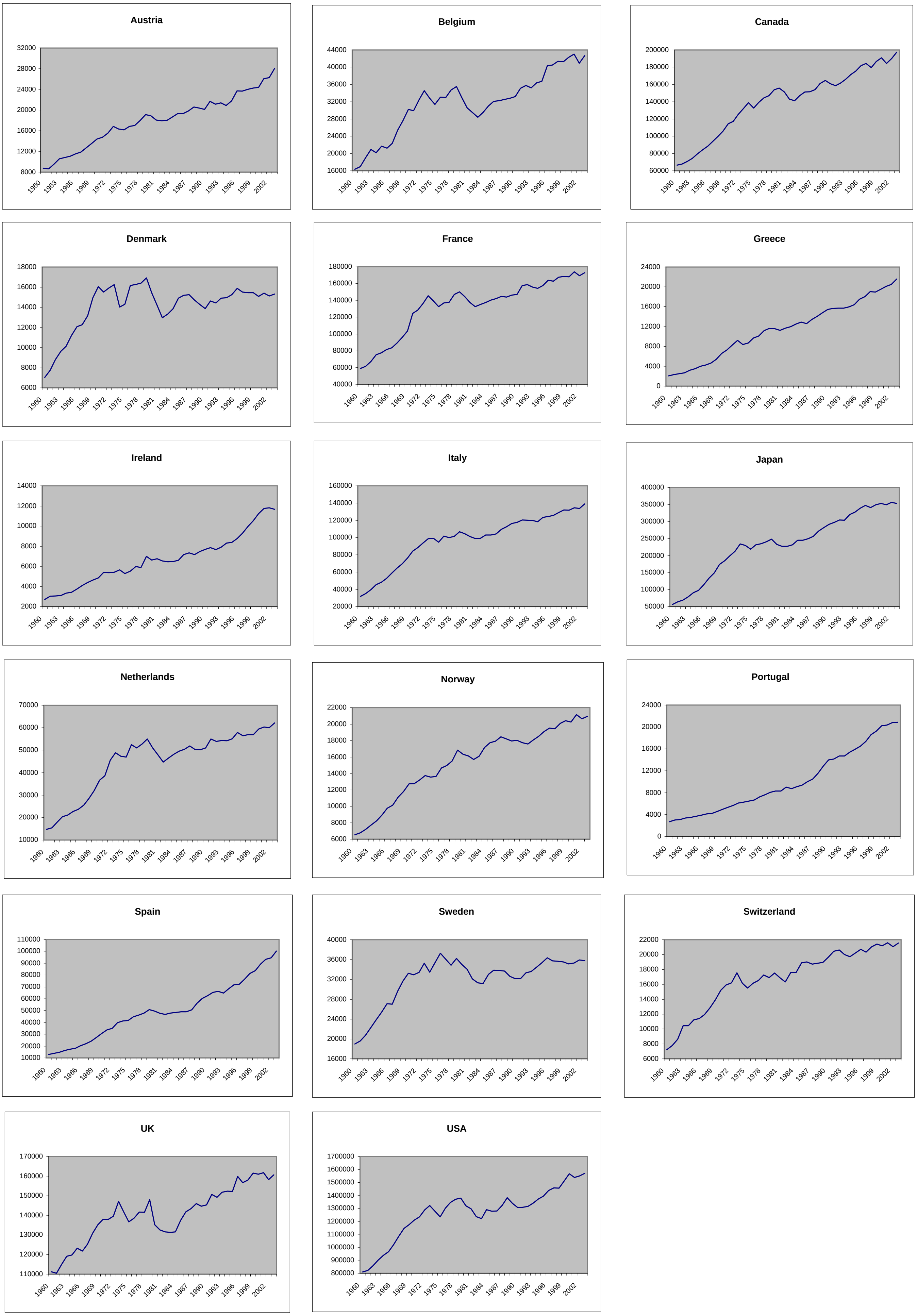

Figure 2: GDP (1995 US$ billions)

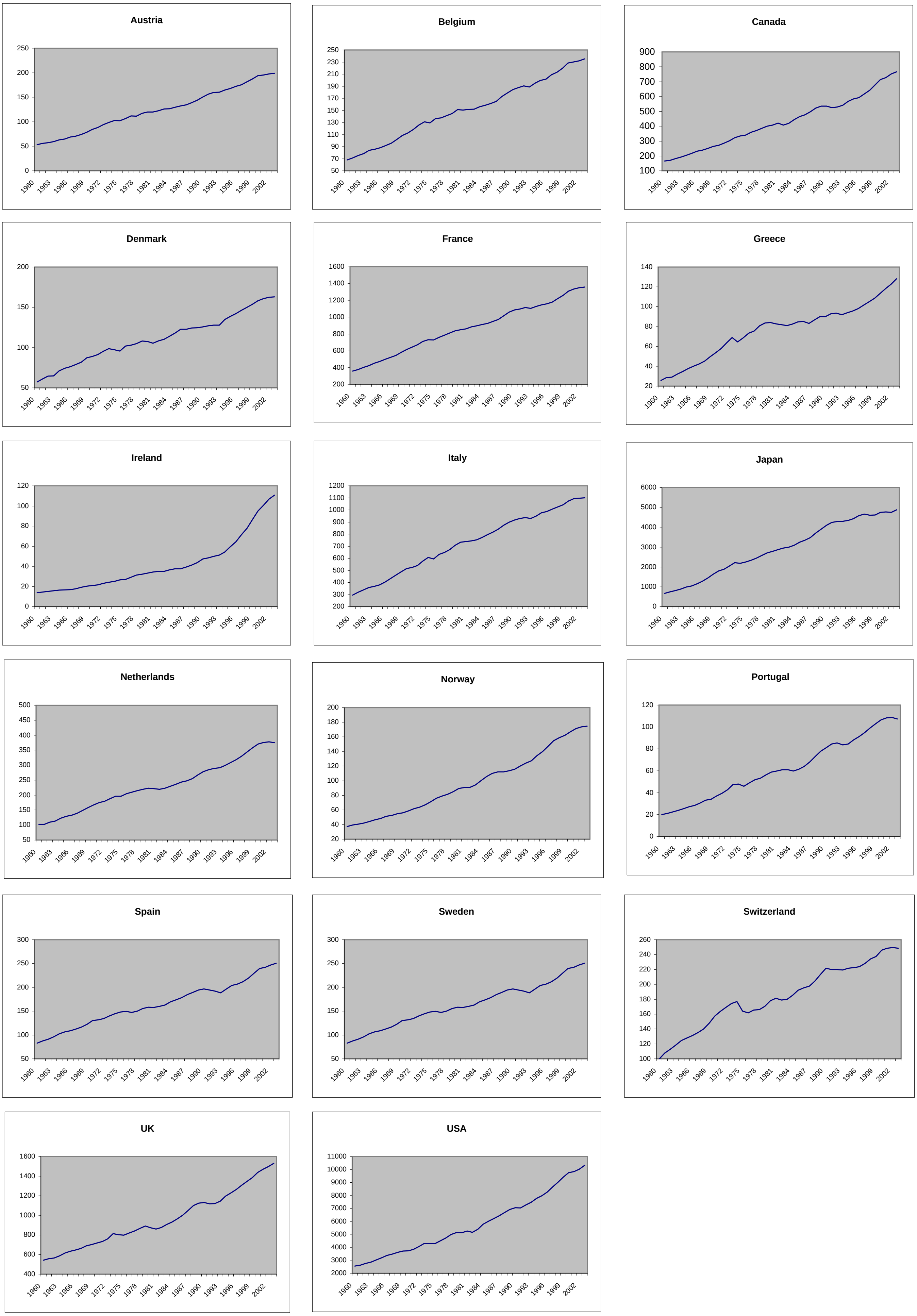

Figure 3: Real Energy prices (2000=100)

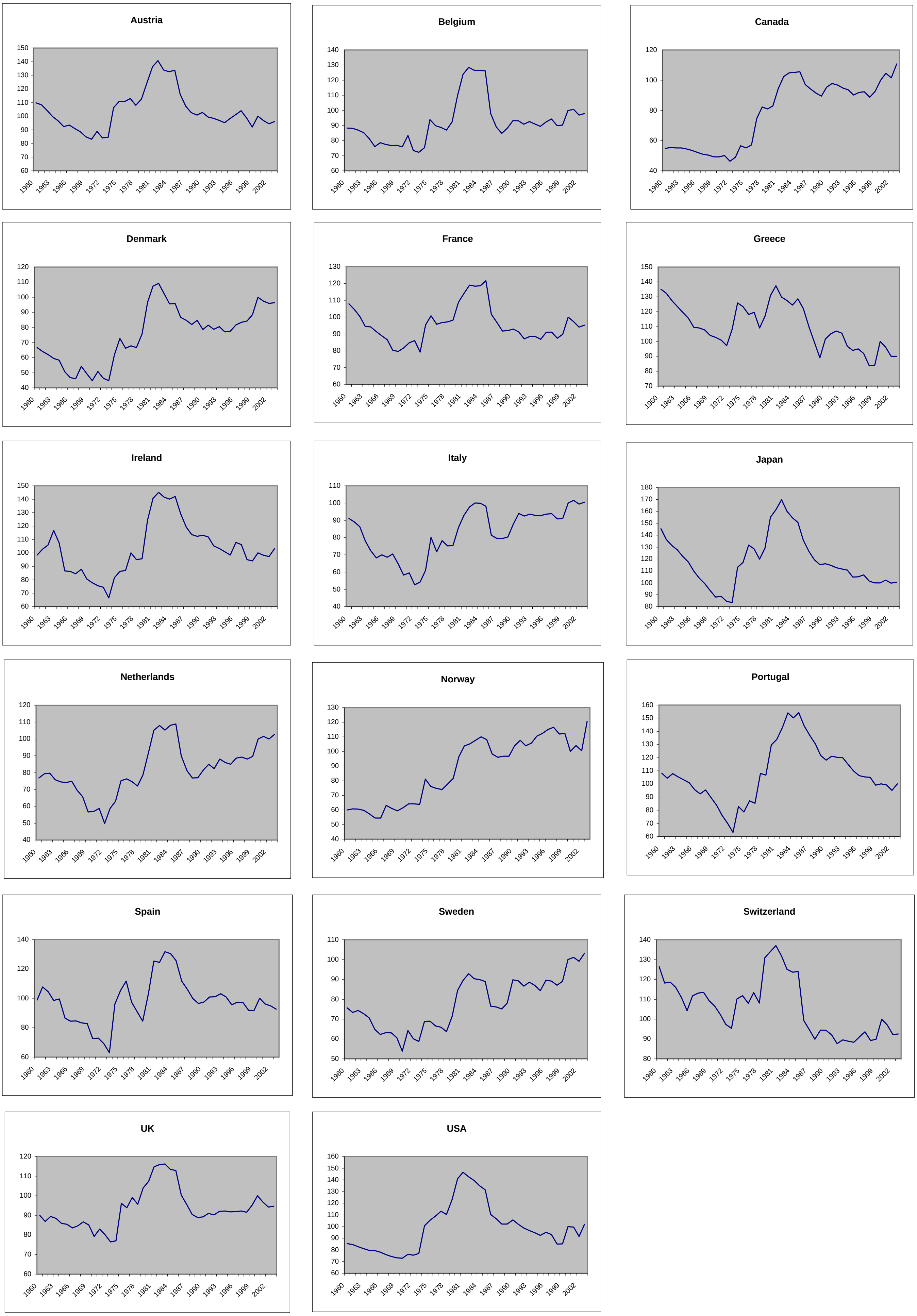

Figure 4: Energy Intensity (1970=100)

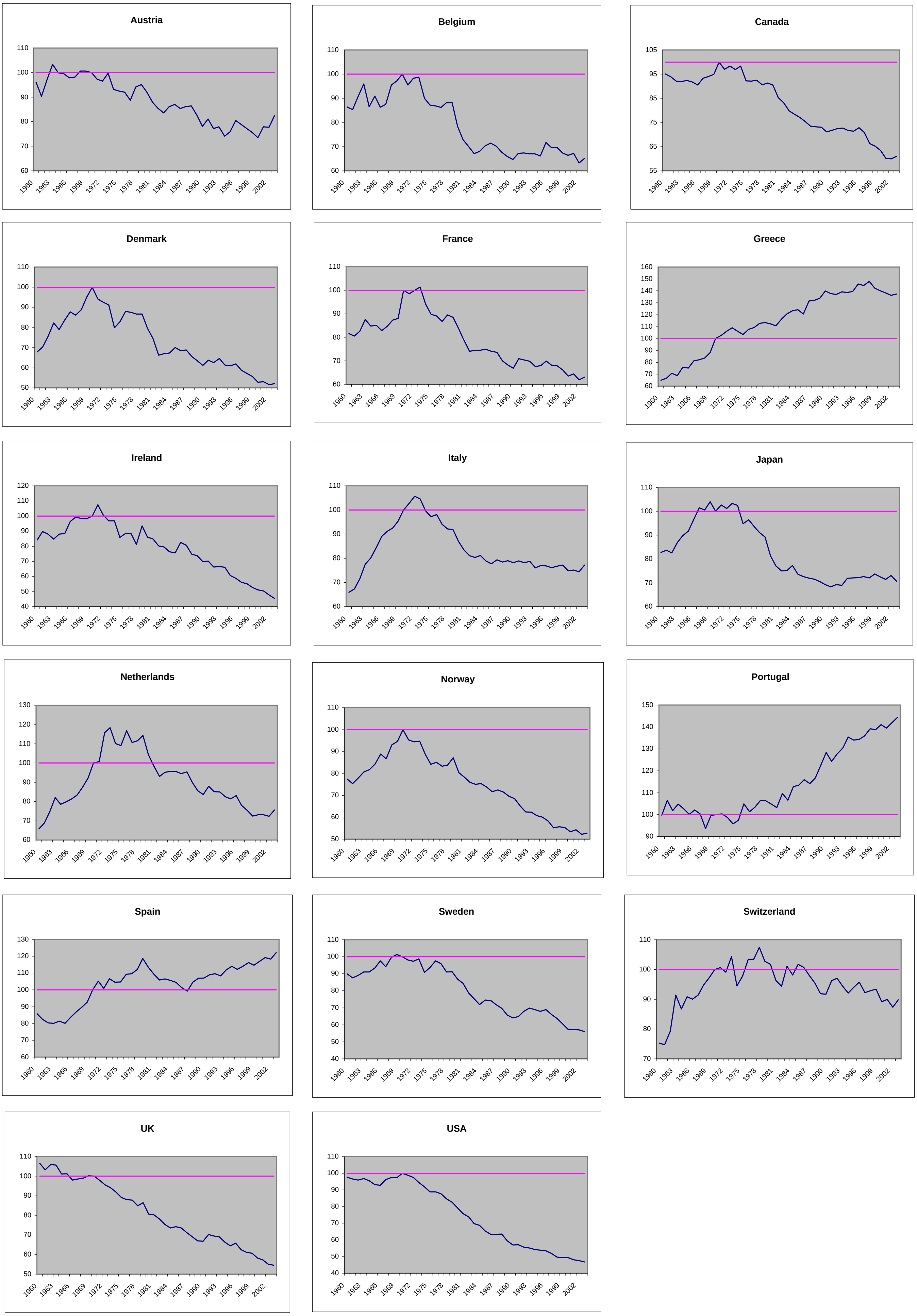

Figure 5: Estimated UEDTs (1970=100)

<u>Note:</u>

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