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Modelling Technical Progress: An Application of The Stochastic Trend Model To UK Energy Demand

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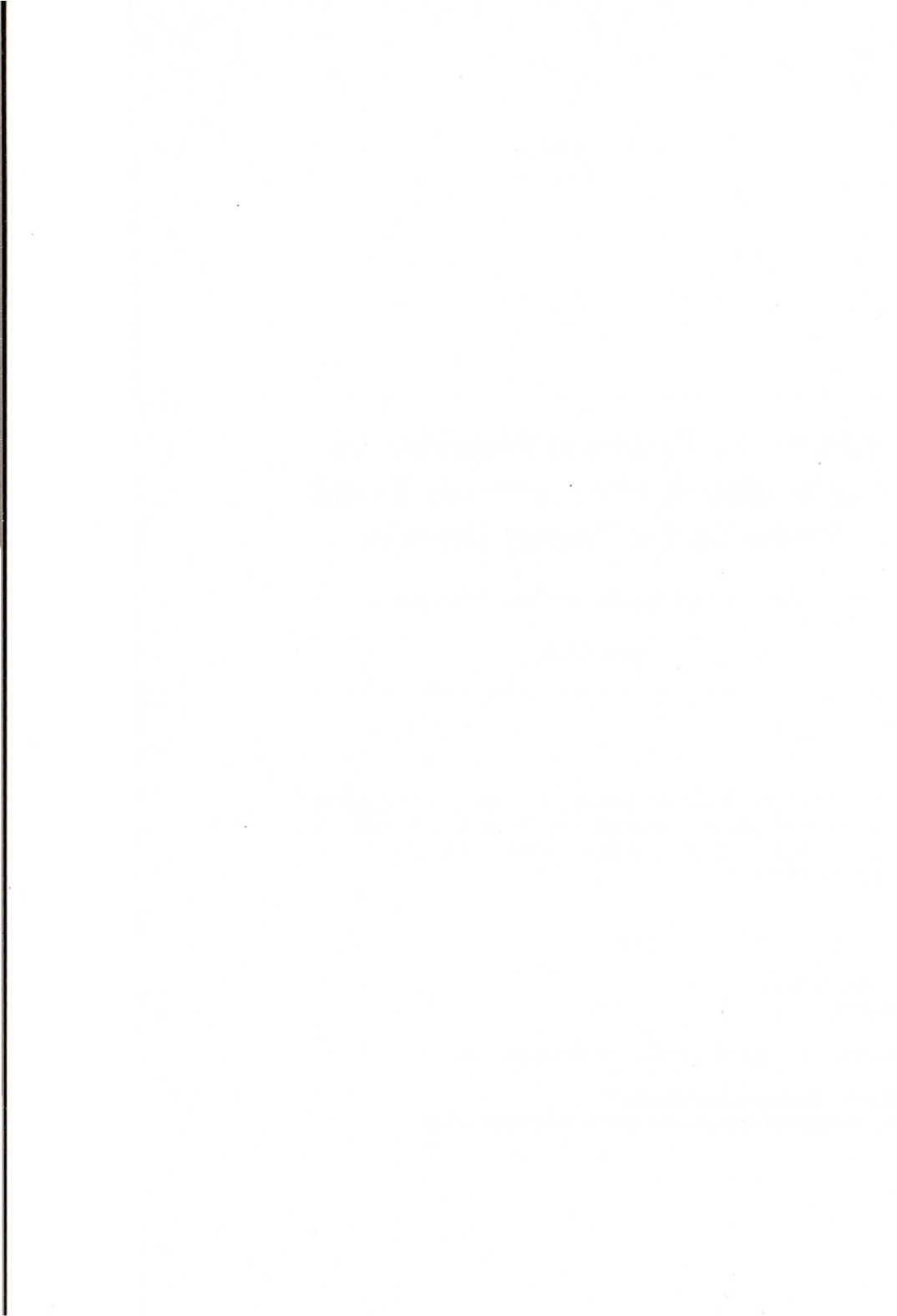
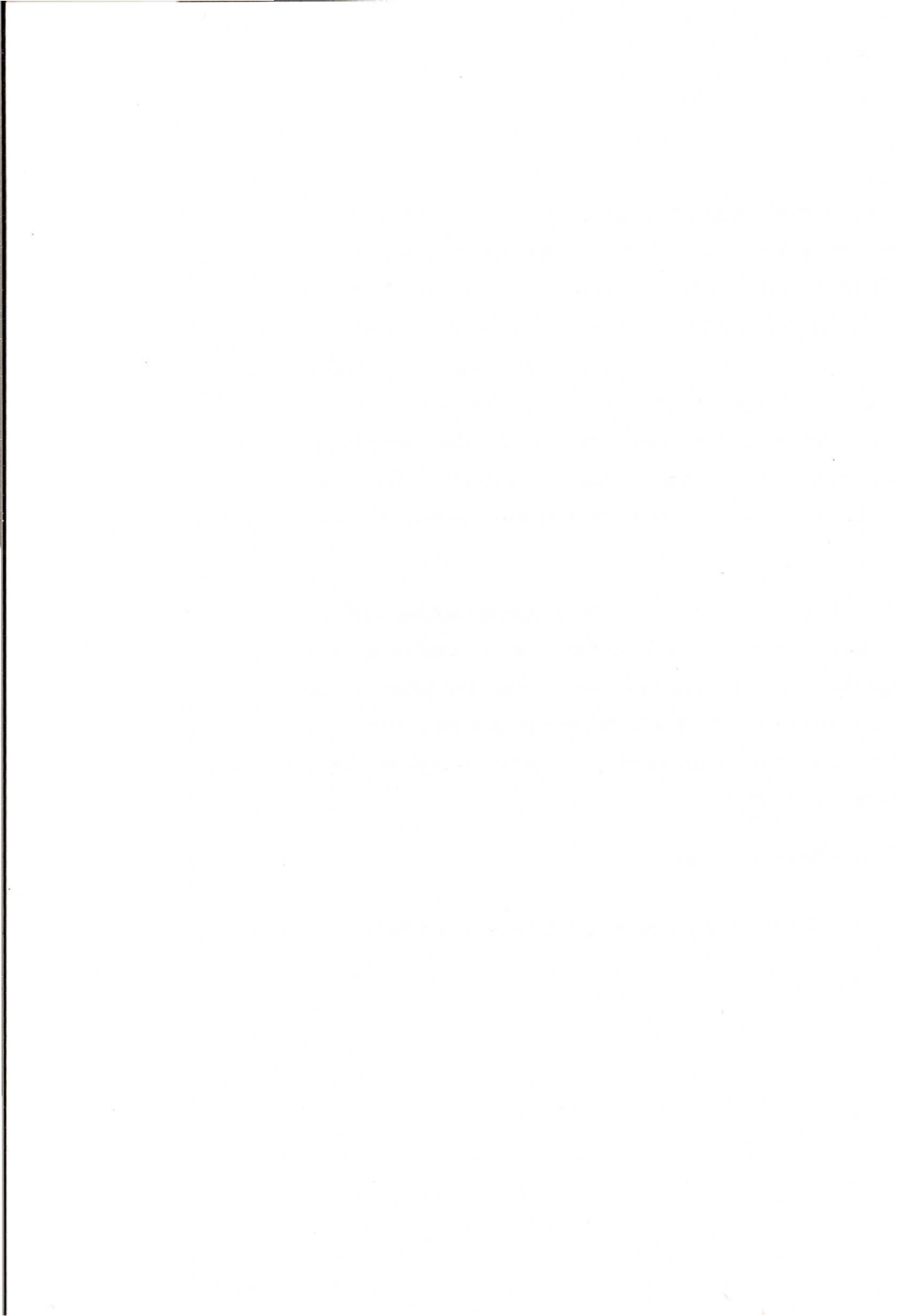Lester C Hunt, Guy Judge and Yasushi Ninomiya

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ABSTRACT

The precise role of technical progress in estimated energy demand functions has not been well researched. Traditionally a deterministic time trend has been used, implicitly assuming technical progress continues at a fixed rate over time. In this paper, the structural time series model is employed allowing for a stochastic time trend and stochastic seasonal dummies. Therefore, technical progress and seasonal variation are treated as unobservable components that evolve over time. The conventional deterministic trend model is a restricted case of the structural time series model and found not to be accepted by the data for a number of energy types.

Energy demand functions for a variety of energy types are estimated for the UK using unadjusted quarterly data. It is found that technical progress in energy usage does not always exhibit a deterministic trend pattern as the conventional model assumes. It often fluctuates over time and is likely to be affected by a range of exogenous factors but also by changes in energy prices (and possibly income also).

JEL Classification Numbers: C52, Q41;

Keywords: energy demand, technical progress, stochastic trend model, seasonality;

I INTRODUCTION

Estimation of Energy Demand functions has a long history with many different methodologies, sectors, and countries analysed. This paper focuses on the modelling of technical progress and the modelling of seasonality. The modelling of technical progress in energy demand functions has tended to be of a very simple nature with it ignored completely or, at best, proxied by a simple deterministic time trend. Similarly, the modelling of seasonality in energy demand functions has traditionally adopted the simple deterministic dummy approach - despite energy being a product where there has been a clear change in the seasonal pattern over time.

It is important to consider exactly what is meant by 'technical progress' when incorporated in energy demand functions. Energy is a *derived* demand, not demanded for its own sake, but for the services it produces in combination with the capital and appliance stock in place at any particular point in time. The challenge for energy demand modellers (and forecasters) is to attempt to distinguish between changes in energy demand that come about through changes in energy prices and income[1], and the underlying changes that come about from 'technical progress'. Jones (1994) points out that 'technical progress' in energy demand, or the improvement in the 'productivity' of energy

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[1] Plus other important variables such as temperature.

use over time, will come about by the improved 'efficiency' of the appliance and capital stock, and hence shift the energy demand curve to the left. Jones goes on, stating that "price increases, if sustained, can … provide the necessary incentive for energy users to find new ways to increase energy's productivity" (p. 245). However, as Jones also points out, many other non-price factors contribute to improvements in the technical progress of energy. These include environmental pressures and regulations, energy efficiency standards, substitution of labour, capital or raw materials for energy inputs, and changes in tastes leading to a shift in consumption towards goods and services that are less energy intensive.

Jones (1994) goes on to argue that the "reductions in aggregate energy demand due to technical progress are distinct from the standard long-run adjustments to price increases that energy consumers make as they gradually replace their energy using capital stock and slowly change their energy consumption habits and patterns" (p. 245). It is important, therefore, to distinguish between the 'price' effects and the 'technical progress' effects. In the short-run, with a fixed appliance and capital stock, a rise in the energy price is likely to bring about a modest fall in energy consumption. Energy consumption will fall further in the long-run as the price rise induces the installation of more energy efficient appliances and capital stock. But, we would argue that this is a combination of the normal process of moving along the long-run demand curve (the long-run

price elasticity) and partly the movement to the left of the demand curve (the technical progress effect). This could be thought of as the long-run price elasticity measuring changes within 'normal bounds' with the technical progress effect picking up price 'shock' effects. Hence, *ceteris paribus*, a model that does not explicitly model technical progress will *over-estimate* the (absolute) long-run price elasticity since it will be forced to pick up both effects.

In addition, contrary to the view of Kouris (1983), we agree with Beenstock and Willcocks (1983) and Welsch (1989), that there is a distinct role for the long-run income elasticity of energy demand within this framework. Increases in income or output will, in the short-run, bring about an increase in energy demand with the given appliance and capital stock (and could be quite significant before households and firms have time to adjust their stock of appliances). Over time however, new and more efficient appliances will be installed and existing appliances replaced faster than would be otherwise. Hence, similar to the price effect a distinction needs to be made between the long-run income effect and the technical progress effect. The increase in income will, in the long-run, bring about an increase in the demand for energy (as new appliances and stock are acquired) which represents the long-run income effect. Furthermore, the increase in income may also induce the replacement of the existing stock of capital with 'up-graded' more efficient models and hence an improvement in energy 'productivity' (which is the

technical progress effect). Here, however, *ceteris paribus*, a specification that that does not explicitly model technical progress might *under-estimate* the long-run income elasticity since it will be forced to pick up both effects.[2]

Whatever factors are driving technical progress it is unlikely that a simple deterministic time trend will adequately capture the underlying processes at play. On this point we agree with Kouris (1983) who stated that a variable "which takes the clumsy values 1, 2, 3, …etc, over time 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). However, he further argues that when modelling energy demand for various sectors there might be certain engineering data [3] that could be considered as a proxy for technical progress, that would be better than 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, our italics). 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). Thankfully, this argument is now redundant given the

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[2] In addition, we would expect, *a priori*, that a dynamic model that does not explicitly model technical progress will *under-estimate* the speed of adjustment towards equilibrium.

[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).

advance in certain econometric techniques. Although the engineering data that Kouris refers to are still not readily available, the Basic Structural Model developed by Harvey and his associates, see for example, Harvey *et al.* (1986), Harvey (1989), Harvey and Scott (1994) and Harvey (1997), allows for a non-linear stochastic trend that, when used in estimates of energy demand functions, overcomes most, if not all, of the problems put forward by Kouris. Moreover, the use of the simple deterministic time trend becomes a limiting case that is present only if statistically accepted by the data.

In summary, we argue that there is a specific role for a general model of energy demand that allows for both short- and long-run price and income elasticities and the most 'general' or 'flexible' form of technical progress possible. This will ensure that the model captures the underlying technical progress effects outlined above avoiding the *upward-bias* of the long-run price elasticity and the *downward-bias* of the long-run income elasticity[4]. Moreover, the more flexible the trend is the smaller these biases are likely to be. Any restriction on the general form, (such as a zero long-run income elasticity, or a deterministic trend) should, therefore, only be imposed if accepted by the data.

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[4] This discussion implicitly assumes that the 'underlying' trend is negative with improvements in energy 'productivity' and hence technical progress reduces energy consumption. If however, the underlying trend is positive and therefore technical progress is negative (due, for example to a fundamental shift in tastes into a particular energy type, as we find with gas below) then the biases would be in the opposite directions.

Turning briefly to the issue of seasonality, Hunt and Judge (1996) explored the evolution of seasonal patterns in some UK energy series, but did not consider the technical progress issue. Again, it is important to start with as general a model as possible with deterministic seasonal dummies as the limiting case. The model outlined in the next section therefore allows for an evolving seasonal pattern over time. Hence, we attempt to explicitly model for both *stochastic* technical progress and *stochastic* seasonality for UK Final Consumption of Coal, Gas, Petroleum, Electricity and Total Energy. The exact definitions and the sources of the data are given in the Data Appendix. Section II, therefore, outlines the methodology employed in the estimation and Section III presents the results. Section IV offers a brief summary and conclusion.

II METHODOLOGY

Given the above discussion the framework adopted for this study combines Harvey's Basic Structural Model (BSM) with the dynamic Error Correction Model (ECM). The ECM is formulated as a BSM to estimate the stochastic trend and stochastic seasonal components in addition to the traditional estimates of short- and long-run price and income elasticities of energy demand as discussed above.

Basic Structural Model (BSM)

The BSM allows for the unobservable trend and seasonal components which are permitted to vary stochastically over time. Consider the following quarterly model:

$$e_t = \mu_t + \gamma_t + \mathbf{Z'}_t\delta + \varepsilon_t \tag{1}$$

where e_t is the dependent variable in logs (energy), μ_t represents the trend component, γ_t represents the seasonal component, ε_t represents the irregular component, $\mathbf{Z}_t$ is a $k \times 1$ vector of explanatory variables in logs (price, income and temperature) and δ is a $k \times 1$ vector of unknown parameters.

Trend Component

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

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \tag{2}$$

$$\beta_t = \beta_{t-1} + \xi_t \tag{3}$$

where $\eta_t \sim NID(0, \sigma_\eta^2)$ and $\xi_t \sim NID(0, \sigma_\xi^2)$.

Equations (2) and (3) represent the *level* and the *slope* of the trend respectively. This process can be interpreted as the trend today is the trend of yesterday plus some growth term plus some unpredictable noise, in which the growth term is the slope and is time-varying. Table 1 illustrates the various models that can be

estimated from this process. Cell (ix) of Table 1 represents the most general model when $\sigma_\eta^2 \neq 0$ and $\sigma_\xi^2 \neq 0$ so that both the *level* and *slope* of the trend change stochastically over the sample period. The remaining cells of Table 1 represent possible restricted alternatives, depending upon the estimates of the *level* and *slope* of the trend and the hyperparameters, σ_ξ^2 and σ_η^2.[5]

Cells (i), (ii) and (v) illustrate the conventional regression models (ignoring evolving seasonals) that are special cases of the general stochastic trend models. When both variances are zero, namely $\sigma_\eta^2 = 0$ and $\sigma_\xi^2 = 0$, the model reverts to a conventional deterministic linear trend model, cell (v), as follows:

$$e_t = \alpha + \beta t + \mathbf{Z}_t' \delta + \varepsilon_t \tag{4}$$

which can be estimated by OLS. If, in addition, the *slope* is found to be zero, slp = 0, then the model reverts to a conventional regression model without a time trend, cell (ii). And if the *level* is also found to be zero, lvl = 0, then the model reverts to a conventional regression with no time trend and no constant, cell (i).

Cells (iii), (vi) and (viii) are restricted versions of the general stochastic trend model but still involve some form of stochastic trend in the *level or slope*. If

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[5] Cells (iv) and (vii) are ignored since it is not possible to estimate models of this type.

TABLE 1: CLASSIFICATION OF POSSIBLE STOCHASTIC TREND MODELS[6]

SLOPE	**LEVEL**		
	No Level $\text{Lvl} = 0, \sigma_\eta^2 = 0$	Fixed Level $\text{Lvl} \neq 0, \sigma_\eta^2 = 0$	Stochastic Level $\text{Lvl} \neq 0, \sigma_\eta^2 \neq 0$
No Slope $\text{Slp} = 0, \sigma_\xi^2 = 0$	**(i)** Conventional regression but with no constant and no time trend	**(ii)** Conventional regression with a constant but no time trend.	**(iii)** Local Level Model *(random walk plus noise)*.
Fixed Slope $\text{Slp} \neq 0, \sigma_\xi^2 = 0$	**(iv)**	**(v)** Conventional regression with a constant and a time trend.	**(vi)** Local Level Model with Drift.
Stochastic Slope $\text{Slp} \neq 0, \sigma_\xi^2 \neq 0$	**(vii)**	**(viii)** Smooth Trend Model.	**(ix)** Local Trend Model.

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[6] The seasonal component is omitted at this stage for simplicity.

$\sigma_\eta^2 \neq 0$ but $\sigma_\xi^2 = 0$ the trend is the *Local Level Model with Drift* provided the

slope is non-zero (slp $\neq$ 0), cell (vi) or the *Local Level Model (random walk with*

drift) if the there is no slope (slp = 0), cell (iii). If, however, $\sigma_\eta^2 = 0$ but $\sigma_\xi^2 \neq 0$

it is the *Smooth Trend Model*, cell (viii).[7]

Seasonal Component

In addition, the 'general' seasonal model allows the component γ_t to have the

following stochastic process:

$$S(L)\gamma_t = \omega_t \tag{5}$$

where $\omega_t \sim NID(0, \sigma_\omega^2)$ and $S(L) = 1 + L + L^2 + L^3$.

The conventional case (ignoring the stochastic trend) is again a restricted

version of this when $\sigma_\omega^2 = 0$ with γ_t reducing to the familiar deterministic

seasonal dummy variable model. If not, however, seasonal components are

moving stochastically over time.[8]

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[7] Boone *et al*. (1995) and Smith *et al*.(1995) have attempted to estimate an aggregate UK primary energy demand function using a different form of stochastic trend model. Their model treats the trend μ_t as an endogenous variable dependent upon exogenous factors such as the energy price and the share of manufacturing output in total GDP. Consequently, only the slope, β_t is considered as "pure" stochastic. In addition, they implicitly impose a long-run income elasticity of unity.

[8] The irregular component ε_t reflects non-systematic movements and is assumed to be white noise

Dynamic (ECM) Models incorporating Stochastic Trend and Seasonals

Harvey, *et al.* (1986) estimated an employment function (using seasonally adjusted data) but incorporating a stochastic trend that fitted well and encompassed rival formulations. Harvey and Scott (1994) estimated an ECM for the UK consumption function that included stochastic seasonal variables and showed that it out performed the standard ECM consumption function with fixed seasonals. Hunt and Judge (1996) found similar results for various energy consumers' expenditure categories.

Therefore, following from these previous works, we estimate an ECM version of equation (1) for UK energy demand as follows:

$$A(L)\Delta e_t = \mu_t + \gamma_t + B(L)\Delta y_t + C(L)\Delta p_t + \lambda(e_{t-1} - \alpha_1 y_{t-1} - \alpha_2 p_{t-1}) + \psi \text{TEMP}_t + \varepsilon_t$$

$$(6)$$

where $A(L)$ is the polynomial lag operator $1 - \phi_1 L - \phi_2 L^2 - \phi_3 L^3$, $B(L)$ the polynomial lag operator $\pi_0 + \pi_1 L + \pi_2 L^2 + \pi_3 L^3$, and, $C(L)$ the polynomial lag operator $\varphi_0 + \varphi_1 L + \varphi_2 L^2 + \varphi_3 L^3$. e_t is the natural logarithm of the energy series, y_t the natural logarithm of GDP, p_t the natural logarithm of the real price of that form of energy, and TEMP$_t$ the average temperature. α_1 and α_2 represent the long-run income and price elasticities respectively, ψ represents

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i.e. $\varepsilon_t \sim NID(0, \sigma_\varepsilon^2)$

the effect of a change in temperature on energy demand and λ the coefficient on the EC term. μ_t, γ_t, and ε_t are as defined above.

Estimation

The estimated equation therefore consists of equation (6) with (2) (3) and (5). All the disturbance terms are assumed to be independent and mutually uncorrelated with each other. As seen above, the hyperparameters σ_η^2, σ_ξ^2, σ_ω^2, and σ_ε^2 have an important role to play and govern the basic properties of the model. The hyperparameters, along with the other parameters of the model are estimated by maximum likelihood and from these the optimal estimates of β_T, μ_T and γ_T are estimated by the Kalman filter which represent the latest estimates of the *level* and *slope* of the trend and the seasonal components. The optimal estimates of the trend and seasonal components over the whole sample period are further calculated by a smoothing algorithm of the Kalman filter. The software package STAMP 5.0 (Koopman *et al.*, 1995) was used to estimate the models for each of the energy series, the results of which are given in the following section.

III RESULTS

Equation (6) was estimated for Coal, Gas, Petroleum, Electricity, and Total Energy using quarterly data from 1972q1 to 1995q4 saving three years (12 observations) for the post-sample prediction tests. The preferred models for each fuel types are given in Table 2. The methodology employed was to select a suitable restricted model by testing down from the over-parameterised model of equation (6) which satisfied parameter restrictions without violating the diagnostic tests detailed in Table 2. The Likelihood Ratio (LR) test was normally used when choosing between different restrictions regarding the hyperparemeters.[9] Finally the preferred model for each energy-type was re-estimated and tested, via the LR test, for the following restrictions:

(a)　deterministic seasonal dummies;

(b)　a deterministic time trend;

(c)　a deterministic time trend with deterministic seasonal dummies;

(d)　no trend;

(e)　no trend with deterministic seasonal dummies.[10]

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[9] Testing for zero restrictions on various hyperparameters occasionally resulted in an *increase* in the Log-Likelihood value, which rendered the LR test invalid. However, Harvey (1985) states that these kinds of tests are subject to some statistical problems (p. 220). Therefore, goodness of fit measures, diagnostic tests, etc were used as a guide.

[10] Although not all tests were feasible for all energy types given they were non-nested.

Table 2: Estimated Elasticities, Hyperparemeters and Diagnostics from the ECM/BSM models, 1972q1 - 1995q4

	COAL	GAS	ELECTRICITY	PETROLEUM	TOTAL ENERGY
Elasticity Estimates					
Long-Run Income	1.688	0.675	0.817	0.835	0.534
Short-Run Income	0.950	0.526	0.672	0.583	0.645
Long-run Price	0	0	0	-0.150	-0.182
Short-Run Price	0	0	-0.286	-0.101	-0.158
Estimated Coefficients					
Temperature	-0.018	-0.043	-0.021	-0.011	-0.023
EC	-0.665	-0.932	-0.919	-0.659	-0.868
Estimated Hyperparemeters					
$\sigma_\varepsilon^2 \times 10^{-4}$	23.117	3.846	0.551	2.151	2.000
$\sigma_\eta^2 \times 10^{-4}$	1.297	0	1.062	0	0.647
$\sigma_\xi^2 \times 10^{-4}$	0	0.059	0	0.017	0
$\sigma_\omega^2 \times 10^{-4}$	0.640	3.398	0.491	1.296	0.110
Nature of Trend	Local level Model with Drift	Smooth Trend Model	Local Level Model	Smooth Trend Model	Local Level Model
Diagnostics					
Standard Error	5.59%	4.03%	2.03%	2.63%	2.02%
Normality	0.51	0.76	1.05	0.15	0.18
H(30)	0.65	1.46	1.22	0.65	0.46
r(1)	0.01	-0.06	0.00	0.06	-0.12
r(8)	0.21	0.01	-0.03	-0.01	0.05
DW	1.91	2.09	1.99	1.88	2.09
Q(8,6)	7.72	4.97	2.27	4.11	5.93
R_s^2	0.85	0.94	0.92	0.93	0.92
Predictive Tests (96q1-98q4)					
$\chi^2_{(12)}$	8.02	41.02**	9.99	3.82	8.77
Cusum _t_	-0.82	0.25	-0.63	0.44	0.47
LR tests					
Test a) $\chi^2_{(1)}$	6.59*	105.68**	69.39**	111.20**	5.86*
Test b) $\chi^2_{(1)}$	5.45*	58.30**	n/a	22.38**	n/a
Test c) $\chi^2_{(2)}$	11.48**	134.57**	n/a	132.60**	n/a
Test d) $\chi^2_{(2)}$	19.42**	44.09**	63.19**	6.29*	30.11**
Test e) $\chi^2_{(3)}$	24.87**	122.79**	100.05**	119.90**	36.10**

H(30) is the test for heteroscedasticity, approximately distributed as $F_{(30, 30)}$;

r(1) and r(8) are the serial correlation coefficients at the 1st and 9th lag respectively;

DW is the Durbin Watson Statistic;

Q(8,6) is the Box-Ljung Q-statistics based on the first 8 residuals autocorrelations and distributed as $\chi^2_{(6)}$;

R_s^2 is the coefficient of determination based on the differences around the seasonal mean;

$\chi^2_{(12)}$ is the post-sample prediction failure test;

The Cusum t is the test of parameter consistency, approximately distributed as the t-distribution.

2. The restrictions imposed for the LR tests are explained in the text (** indicates significant at the 1% level and * indicates significance at the 5% level).

3. The coal equation included impulse dummies for 1974q1, 1980q1, 1984q2. The Petroleum equation included an impulse dummy for 1981q1. These, were included to ensure the residuals were white noise, in particular to ensure normality.

This acted as a final check to ensure that the stochastic versions were always accepted by the data and allowed for a comparison of the estimated long-run price and income elasticities.

Overall the models appear to fit the data very well with almost all diagnostic tests passed. The LR tests clearly indicate that the stochastic seasonal specifications are superior to deterministic seasonal dummies[11], hence further discussion will be limited given the space constraint.[12] The LR tests also indicate that in all cases some form of stochastic specification for technical progress is preferred to the deterministic time trend or no trend at all. It is also clear that various types of stochastic processes are found for the different energy types which are discussed in more detail below.

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[11] This is despite the temperature variable being consistently significant.
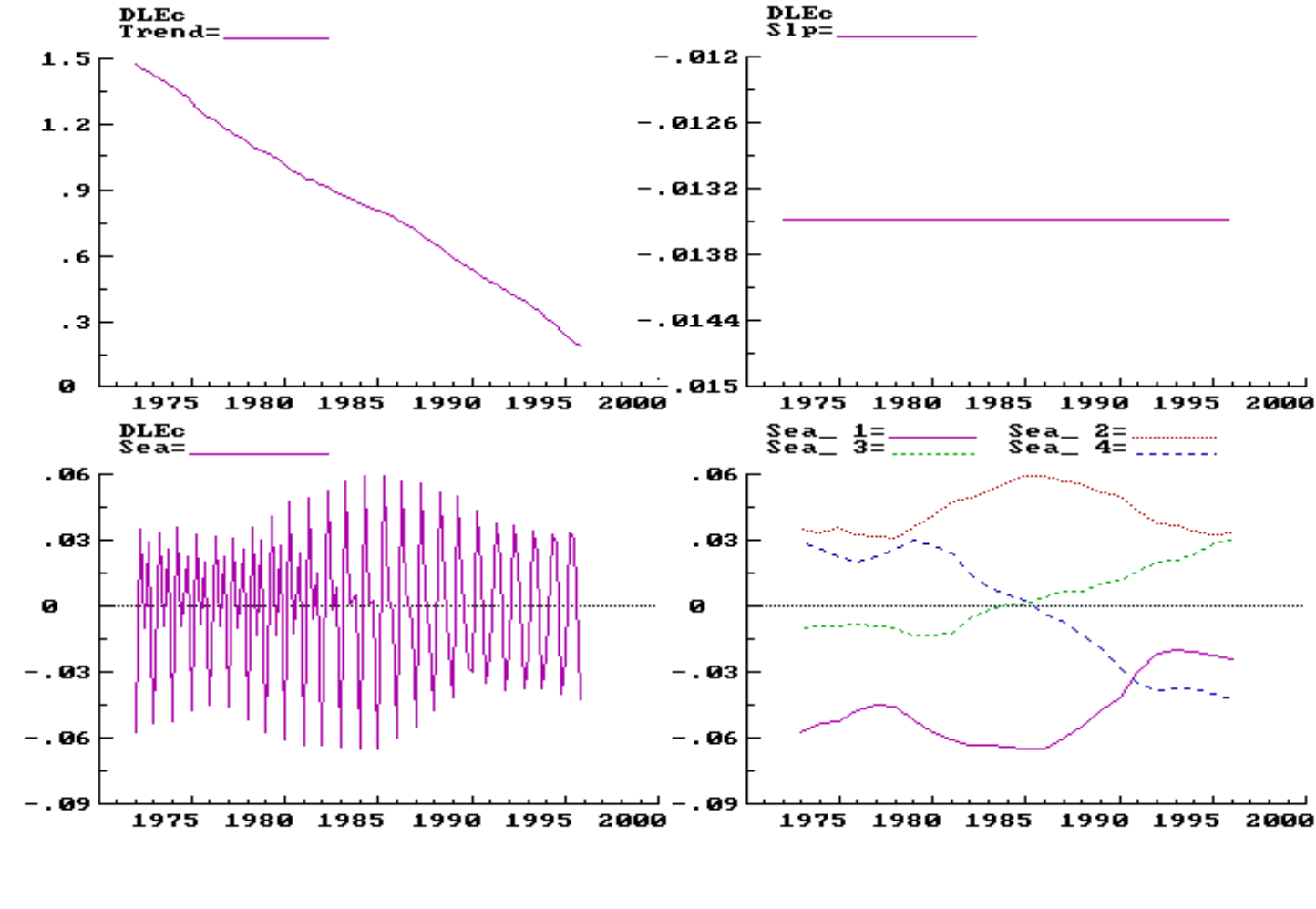
[12] However, the evolving seasonals for each energy type are presented in Figures 1 – 5 as an illustration.

Coal

The preferred specification for coal finds no role for price in either the short and the long run. The estimated income elasticities of 0.95 and 1.69 in the short- and long-run respectively are surprisingly high. The estimated trend is the Local Level Model with Drift and is illustrated in the top left hand chart of Figure 1. This clearly indicates a long term underlying fall in the demand for coal of about -5.3% per year and although the hyperparemeter σ_η^2 is non-zero, there is little variation around this trend. Interestingly, when the trend is omitted completely, tests (d) and (e), the long-run income elasticity is negative and significant suggesting that Coal is an inferior good similar to the results of Fouquet, *et al.* (1993 and 1997). This is clearly due to the omission of any 'technical progress' term to model the long term decline of coal and hence an under-estimate of the long-run income elasticity. It is appropriate, therefore, to include a measure of technical progress in the coal demand model to separate out the 'exogenous' effect from the (positive) income effect. That said however, the high income elasticity estimates obtained here are difficult to justify intuitively.[13]

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[13] It should be emphasised that this is final consumption and therefore excludes the electricity generation sector where the majority of coal is consumed.
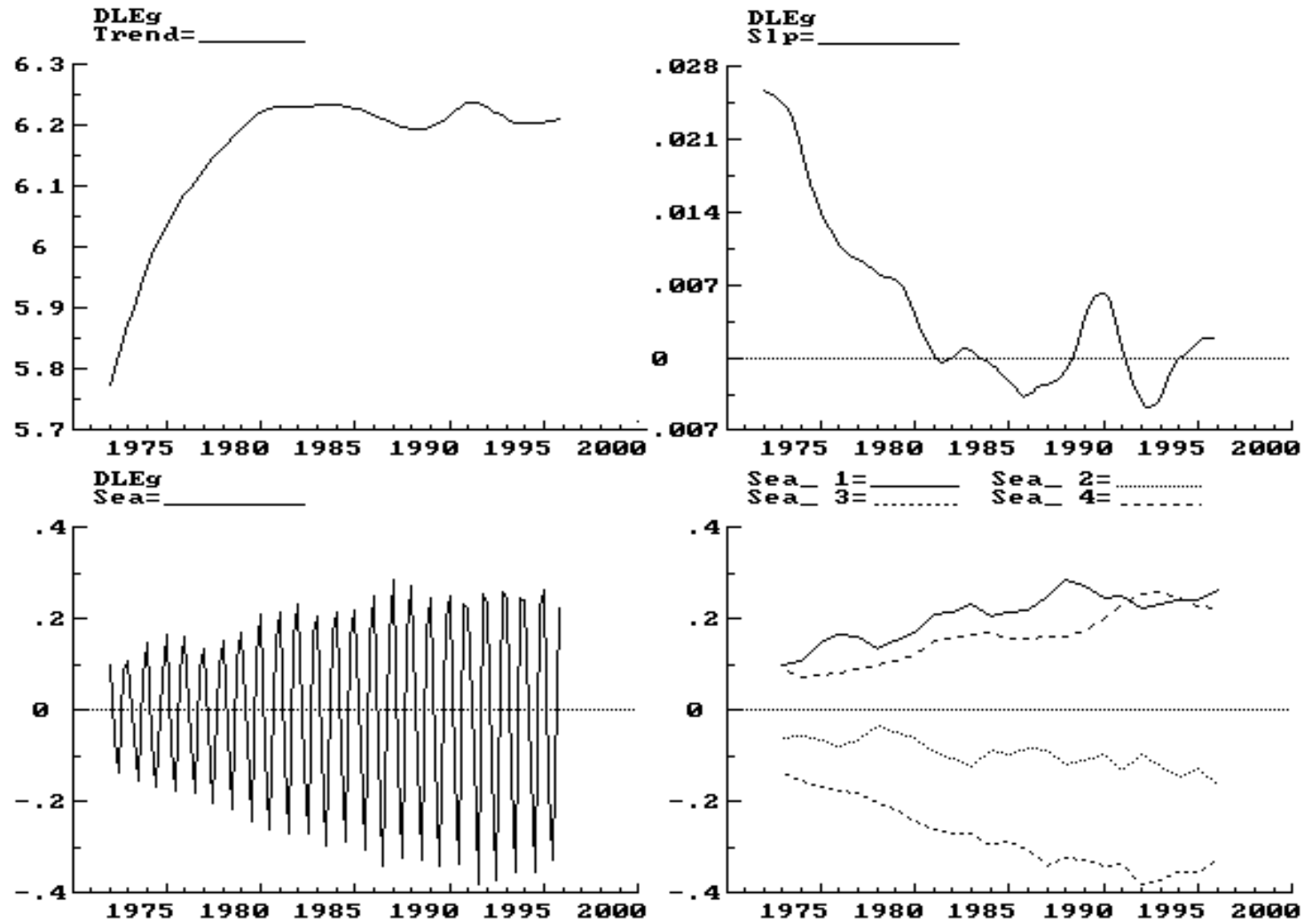
Figure 1: Coal

Gas

When estimating the gas demand function it did not prove possible to produce an equation that passed all diagnostic tests. The preferred equation therefore suffers from some slight instability since it fails one of the predictive failure tests. The preferred specification, similar to coal, does not include a role for price. The long-run and short-run income elasticities are 0.67 and 0.53 respectively being generally lower than those obtained by Fouquet, *et al.* (1993 & 1997) although their specifications included prices but no trend. Here the Smooth Trend Model was preferred, but gives 'negative' technical progress during the 1970s but flattens out in the 1980s and 1990s (as illustrated by the top left hand chart of Figure 2). This probably reflects the 'exogenous' shift in tastes away from town gas and solid fuel during the 1970s. However, the shape of the slope (illustrated in the top right hand chart of Figure 2) would suggest that there were changes (albeit small relative to the 1970s) about the mid 1980s and early 1990s.
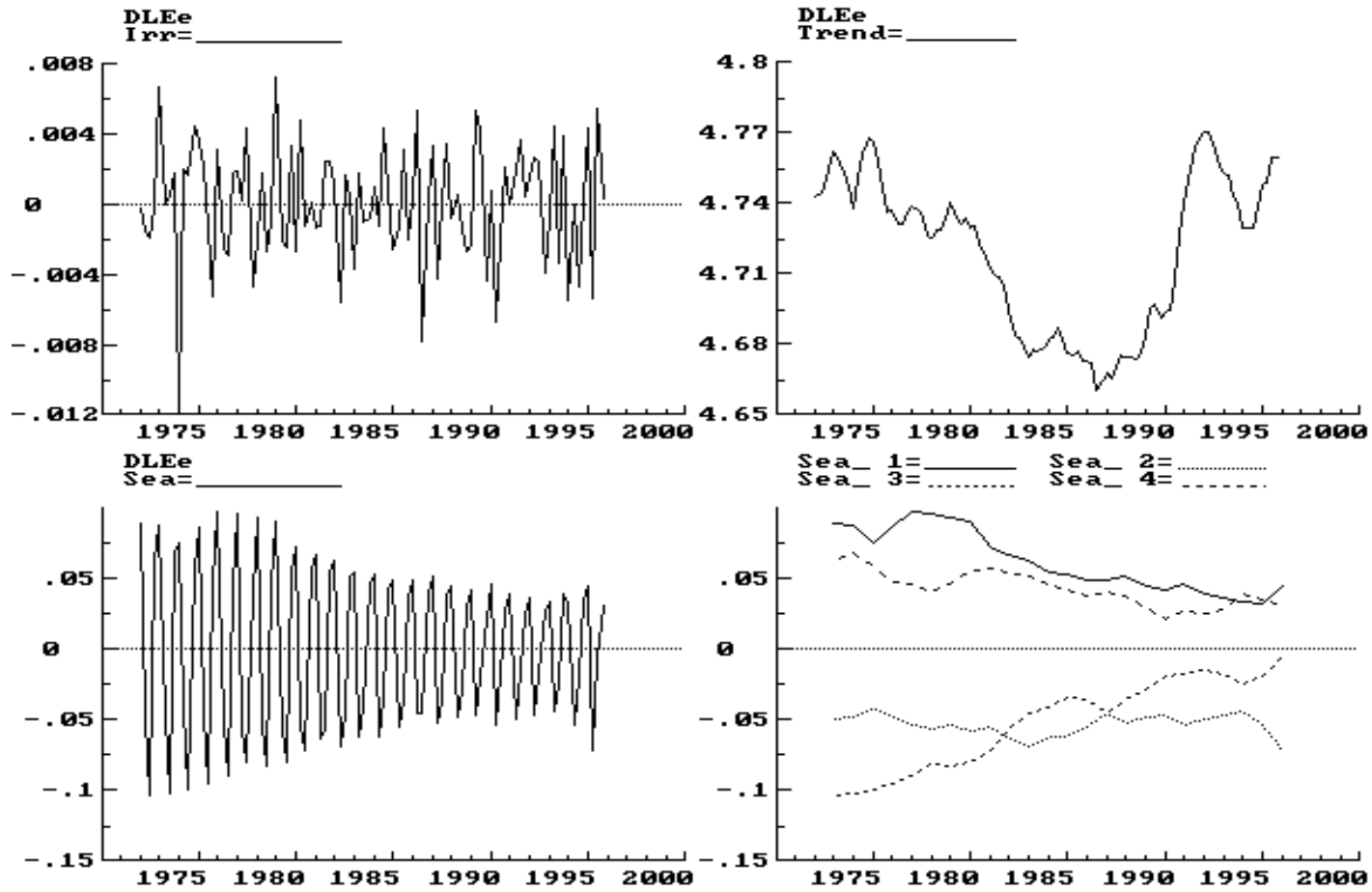
Figure 2: Gas

Electricity

The preferred specification finds only a short-run role for prices with an estimated elasticity of -0.29, with short- and long-run income elasticities of 0.67 and 0.82 respectively. Again these are generally higher than those obtained by Fouquet, *et al.* (1993 & 1997). The Trend is found to be the Local Level Model (as illustrated in the top right hand chart of Figure 3) where there is no slope term but the variation in the trend comes through via the level. Despite there being no slope the shape of the trend shows an interesting pattern, reflecting different phases of technical progress: approximating to the 1970s, the early 1980s, the late 1980s/early 1990s and the mid 1990s. When comparing the electricity trend with the price series (top right hand chart of Figure 6) there would appear to be a close (inverse) relationship.
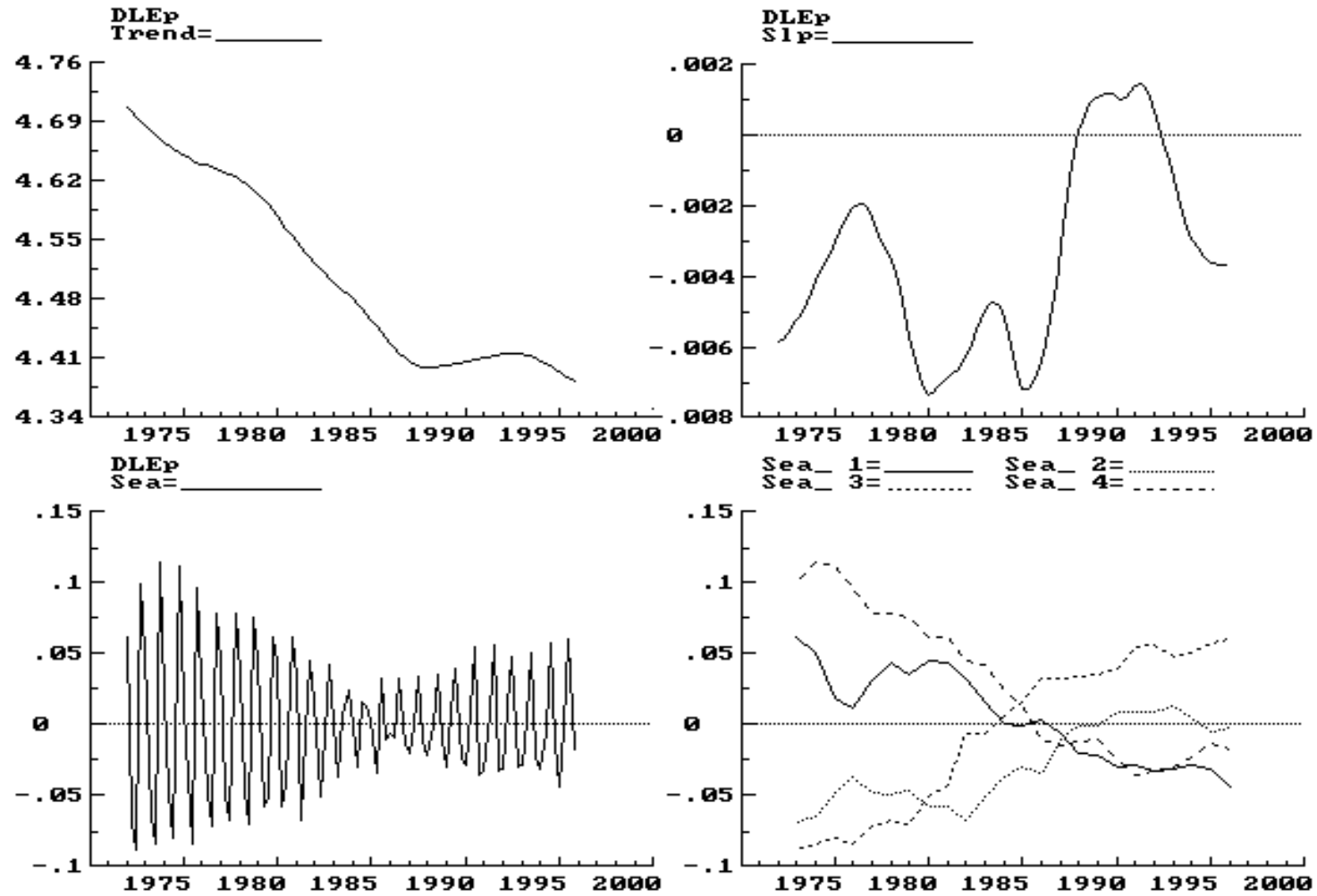
Figure 3: Electricity

Petroleum

The preferred specification gives estimates of 0.84 and -0.15 for the long-run income and price elasticities respectively with the Smooth Trend Model. The trend is illustrated in the top left hand chart of Figure 4 and again produces clear phases of technical progress. There appears to have been a distinct slow down in technical progress in the late 1970s followed by a resumption of a rapid decline during the early 1980s. This decline halted about 1986/7 when there was a distinct slowdown that continued until about 1993 when the progress continued again.[14] The top right hand chart of figure 4 illustrates that this is driven by the stochastic slope which would appear to be inversely linked to real energy price index used for petroleum (see the bottom left hand chart in Figure 6).

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[14] In fact technical progress became 'negative' for a period during the very late 1980s early 1990s as the UK economy moved onto recession.
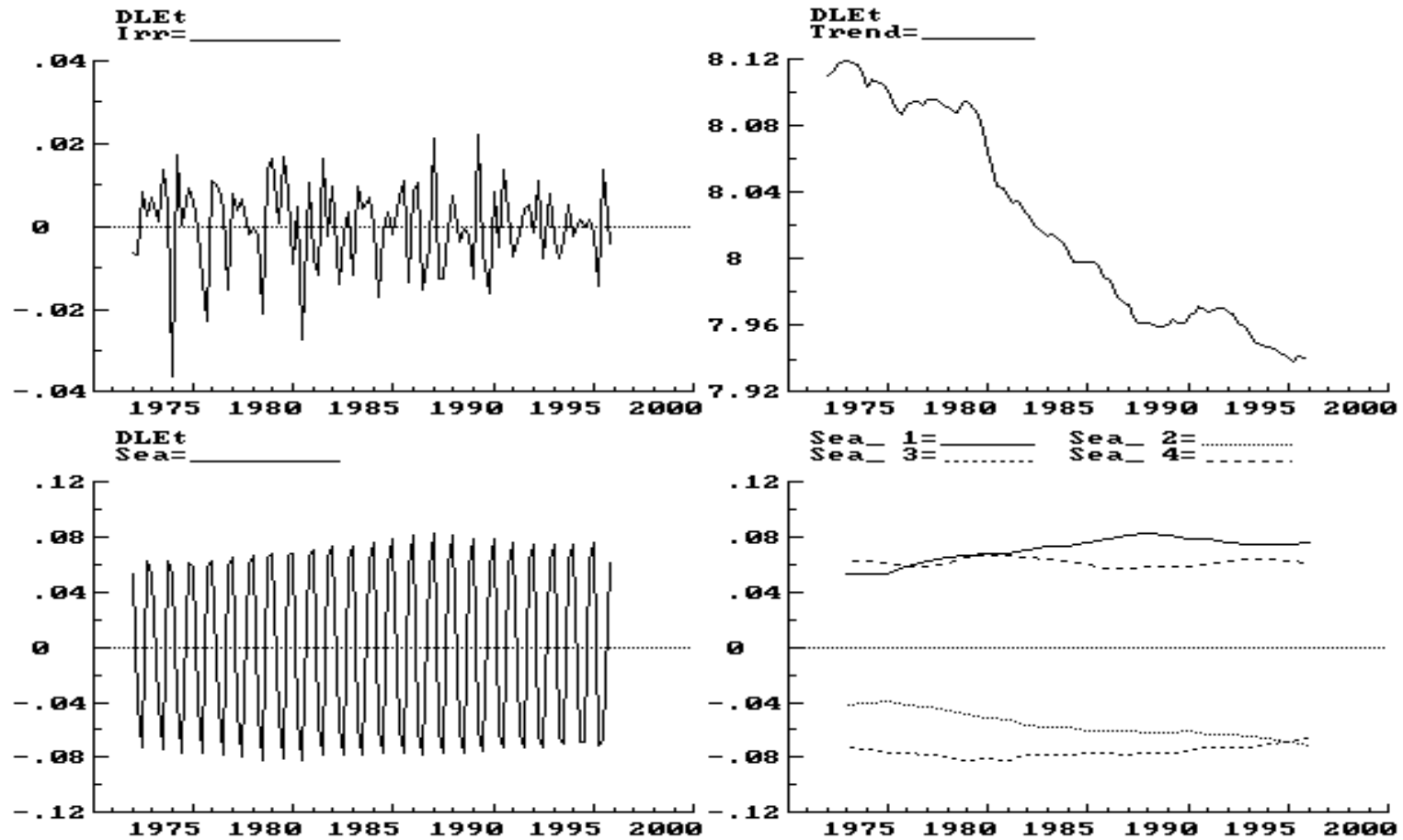
Figure 4: Petroleum

Total Energy

The estimated equation for total energy gives a long-run income elasticity of 0.53 with a larger short run figure of 0.65. Although the elasticities are a little larger (probably due to the inclusion of technical progress terms) this differential of the short to the long run is similar to the annual studies by Hunt and Manning (1989) and Hunt and Witt (1995). The long- and short-run price elasticities are -0.18 and -0.16 respectively. These estimates are in contrast to the recent results by Clements and Madlener (1999) who estimated a range of annual and quarterly models for UK residential aggregate energy demand.[15] They conclude by stating that they were "unable to reject a zero price elasticity" (p. 185). Returning to our results the preferred trend is the Local Level Model and, as with Electricity, despite the slope being zero, the trend still exhibits aninteresting shape as illustrated in the top right hand chart of Figure 5. Although it is not as smooth, since the source of the stochastic trend is different, the general pattern is very similar to that found for petroleum, and appears to be (inversely) related to the price series (and possibly income during the recession of the early 1990s).

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[15] Clements and Madlener (1999) do specify a deterministic time trend but no results are presented in the paper for the trend.
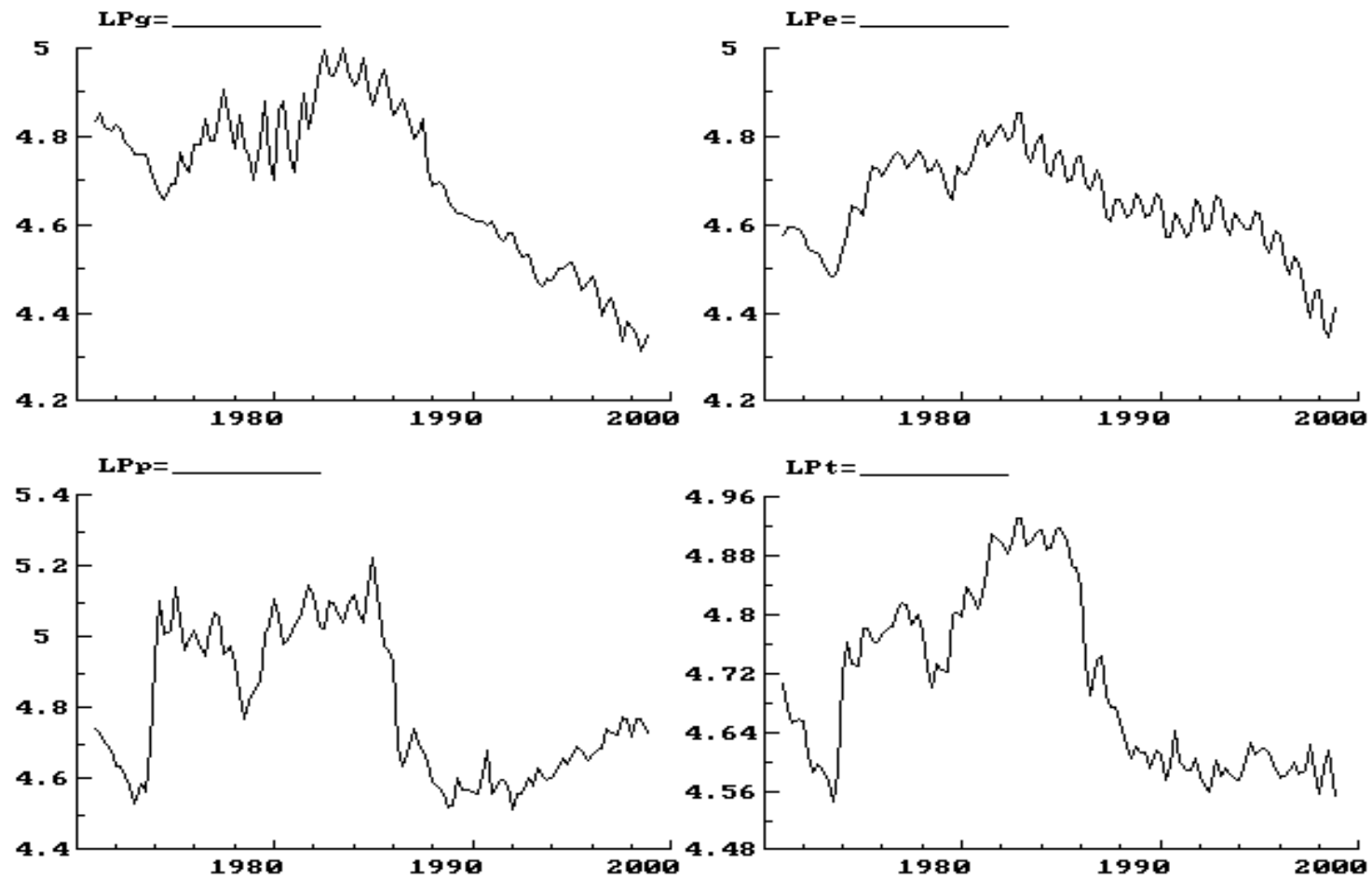
Figure 5: Total Energy

IV SUMMARY AND CONCLUSION

In this paper we have discussed the importance of, not only modelling technical progress when estimating energy demand functions, but also modelling it in a non-linear flexible way. We argue that technical progress comes about from a number of exogenous factors but could also be induced by price and income 'shocks'. It is important, therefore, to incorporate the most flexible possible specification and test down for the most appropriate specification that best fits the data.

We have found for all UK energy types that a specification including some form of technical progress is preferred to one where it is omitted. Moreover, specifications that incorporate a non-linear trend term for technical progress are preferred to the traditional assumption of a deterministic linear time trend. The results suggest that in the UK there have been distinct phases in the process of technical progress as illustrated above. At present it is not possible to determine when these phases are driven by exogenous factors or when they are driven by endogenous factors such as changes in price (and possibly income) as inspection of the charts suggest. A full explanation is hopefully the basis of future research.

Figure 6: Prices

DATA APPENDIX

The data set is quarterly seasonally unadjusted for the period 1971q1 to 1998q4.

Energy Consumption

The energy consumption data (E_t) refers to UK Final Consumption of 'coal', 'gas', 'petroleum', electricity' and 'total energy' in million tonnes of oil equivalent (mtoe) from various issues of the *UK Energy Trends* up to June 1999. Data before 1992 have been converted to mtoe from millions of therms. The 'coal' series refers to coal and other solid fuels and 'gas' includes town and natural gas.

Gross Domestic Product

The nominal and constant prices expenditure estimates of UK Gross Domestic Product GDP(E) at market prices were kindly supplied by the Office of National Statistics (ONS) since the seasonally unadjusted data are not published. Y_t is the constant GDP(E) series re-based and indexed to 1990 = 100. The implicit GDP(E) price deflator at 1990=100 was calculated from the nominal and constant price series.

Energy Prices

The nominal price index for each energy type were derived by weighting the appropriate GB Domestic and Industrial Fuel Price Indices from various issues of the *UK Energy Trends* up to June 1999. The real index of energy prices (P_t) for each energy type was found by deflating the nominal index by the implicit GDP(E) deflator. The 'total energy' price was derived as a weighted average of the individual energy types.

Temperature

$TEMP_t$ refers to the average GB quarterly temperature in degrees Celsius taken from various issues of the *UK Digest of Energy Statistics (DUKES)*.

REFERENCES

Beenstock, M. and Willcocks, P. (1983), 'Energy and Economic Activity: A Reply to Kouris', *Energy Economics*, Vol. 5, No. 3, p. 212.

Boone, L., Hall, S., Kemball-Cook, D. and Smith, C. (1995), 'Endogenous Technological Progress in Fossil Fuel Demand' in Barker, T., Ekins, P. and Johnstone, N. (eds.), *Global Warming and Energy Demand*, Routledge, London.

Clements, M. P. and Madlener, R. (1999), 'Seasonality, Cointegration, and Forecasting UK Residential Energy Demand', *Scottish Journal of Political Economy*, Vol. 46, No. 2, pp. 185-206.

Fouquet, R., Hawdon, D., Pearson, P., Robinson, C. and Stevens, P. (1993), *The SEEC United Kingdom Energy Demand Forecast (1993 - 2000)*, Surrey Energy Economics Centre Occasional Paper 1, Department of Economics, University of Surrey, Guildford.

Fouquet, R., Pearson, P., Hawdon, D. and Robinson, C. (1997), 'The Future of UK Final User Energy Demand', *Energy Policy*, Vol. 25, No. 2, pp. 231 - 240.

Harvey, A. C. (1985), 'Trends and Cycles in Macroeconomic Time Series', *Journal of Business & Statistics*, Vol. 3, No. 3, pp. 216 - 227.

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

Harvey, A. C. (1997), 'Trends, Cycles and Autoregressions', *Economic Journal*, Vol. 107, No. 440, pp. 192 - 201.

Harvey, A. C., Henry, S. G. B., Peters, S. and Wren-Lewis, S. (1986), 'Stochastic Trends in Dynamic Regression Models: An Application to the Employment-Output Equation', *Economic Journal*, Vol. 96, No. 384, pp. 975 - 985.

Harvey, A. C. and Scott, A. (1994), 'Seasonality in Dynamic Regression Models', *Economic Journal*, Vol. 104, No. 427, pp. 1324 - 1345.

Hunt, L. C. and Judge, G. (1996), 'Evolving Seasonal Patterns in UK Energy Series', in Mackerron, G. and P. Pearson (Eds.) *The UK Energy Experience: Model or Warning?*, Imperial College Press, London, pp. 295 - 308.

Hunt, L. C. and Manning, N. (1989), 'Energy Price- and Income-Elasticities of Demand: Some Estimates for the UK using the Cointegration Approach', *The Scottish Journal of Political Economy*, Vol. 36, No. 2, pp. 183 - 193.

Hunt, L. C. and Witt, R. (1995), *An Analysis of UK Energy Demand Using Multivariate Cointegration*, Surrey Energy Economics Discussion Paper SEEDS 86, Department of Economics, University of Surrey, Guildford.

Jones, C. T. (1994), 'Accounting for Technical Progress in Aggregate Energy Demand', *Energy Economics*, Vol. 16, No. 4, pp. 245 -252.

Koopman, S. J., Harvey, A. C., Doornik, J. A., and Shephard, N. (1995), *Stamp 5.0*, International Thompson Business Press, London.

Kouris, G. (1983), 'Energy Consumption and Economic Activity in Industrialised Economies: A Note', *Energy Economics*, Vol. 5, No. 3, pp. 207 - 212.

Smith, C., Hall, S. and Mabey, N., (1995), 'Econometric Modelling of International Carbon Tax Regimes', *Energy Economics*, Vol. 17, No. 2, pp. 133 - 146.

Welsch, H. (1989), 'The Reliability of Aggregate Energy Demand Functions: An Application of Statistical Specification Error Tests', *Energy Economics*, Vol. 11, No. 4, pp. 285 - 292.

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