Modelling Underlying Energy Demand Trends and Stochastic Seasonality: An Econometric Analysis of Transport Oil Demand in the UK and Japan

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MODELLING UNDERLYING ENERGY DEMAND TRENDS AND STOCHASTIC SEASONALITY: AN ECONOMETRIC ANALYSIS OF TRANSPORT OIL DEMAND IN THE UK AND JAPAN

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ABSTRACT

This paper demonstrates the importance of adequately modelling the Underlying Energy Demand Trend (UEDT) and seasonality when estimating transportation oil demand for the UK and Japan. The structural time series model is therefore employed to allow for a stochastic underlying trend and stochastic seasonals using quarterly data from the early 1970s, for both the UK and Japan. It is found that the stochastic seasonals are preferred to the conventional deterministic dummies and, more importantly, the UEDT is found to be highly non-linear for both countries, with periods where it is both upward and downward sloping.

Modelling Underlying Energy Demand Trends and Stochastic Seasonality: An Econometric Analysis of Transport Oil Demand in the UK and Japan[•]

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1. BACKGROUND

This paper attempts to model and estimate oil demand functions for the transportation sectors of the UK and Japan. For both the UK and Japan energy consumption in the transportation sector has increased significantly over past decades. Moreover, the share of total energy consumption by the transport sector has also increased in both countries. In order to fully understand this growth, and more importantly, to predict future energy consumption and the resultant effect on the environment, it is vital that energy demand is modelled appropriately.

It is important to accurately measure the price and income elasticities of demand while at the same time adequately capturing the underlying changes in energy efficiency, and other (usually non-measurable) factors. Energy demand is traditionally modelled as a function of economic activity and the energy price - all normally observable. In addition to these traditional drivers, energy demand is also determined by unobservable factors such as improvements in technical energy efficiency and changes in 'tastes'. In the past these unobservable effects have either i) been ignored or ii) approximated by a simple linear deterministic time trend assuming that the underlying trend is *fixed* over time. In a similar fashion, potential seasonal non-stationarity in seasonally unadjusted data has been ignored, with little attention paid to this in past energy demand studies. Hence, quarterly energy demand studies have traditionally incorporated deterministic seasonal dummy variables to

account for the underlying seasonal pattern. This implicitly assumes that the underlying seasonal pattern is *fixed* throughout the period.

Table 1 presents a selection of recent transportation oil demand studies for the UK, Japan and OECD.[1] Almost all the studies cited use annual data over a range of estimation periods and none of them attempted to use a time trend to capture a 'technical progress' effect. Therefore, in almost all the studies the issue of 'technical progress' and energy efficiency is ignored with the exception of Johansson and Schipper (1997) who include a variable to capture changes in energy efficiency. In addition, Dargay (1992) implicitly attempted to capture the endogenous changes in 'technical progress' via an asymmetric price response model. The table illustrates that there is no consensus with respect to the size of the income and price elasticities for the UK. Unfortunately, for Japan there are very few studies with which to make a comparison. As stated above the studies were predominantly based on annual data. However, the survey by Dahl and Sterner (1991) does discuss the use of quarterly data. They argue that the way quarterly data is treated will affect estimated petrol demand elasticities. Moreover, they state that "researchers should pay close attention to seasonal effects before using such estimates for overall long-run forecasting or policy analysis" (p. 207).

{Table 1 about here}

In this paper, we attempt to estimate the income and price elasticities of demand for transportation oil demand in the UK and Japan using quarterly data between 1971q1 and 1997q4. The structural time series model is employed in place of the conventional deterministic trend model, hence accommodating the unobservable underlying trend in a more 'general' way. Similarly, stochastic seasonal dummies are incorporated in place of conventional seasonal dummies, hence allowing the seasonal pattern to evolve over time. Within this framework, the conventional linear trend model is a (restricted) special case and only accepted if supported by the data. Likewise, the deterministic seasonal dummy model is a (restricted) special case of the more general evolving seasonal model and only accepted if supported by the data.

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[1] Table 1 partly relies on Glaister and Graham (2000) which contains an excellent survey of recent oil

2. UNDERLYING ENERGY DEMAND TREND (UEDT)

It is important to understand what the stochastic trend is attempting to measure in energy demand functions. The debate on whether to include or not include a deterministic linear time trend when estimating energy demand functions has focussed on 'technical progress' - in particular whether it is appropriate to model such a process using a simple linear variable. This implicitly assumes that 'technical progress' results in an improvement in energy productivity or energy efficiency as an activity becomes less energy intensive. Given this restrictive focus we utilise a more general measure of the *Underlying Energy Demand Trend (UEDT)* that encompasses technical progress but also allows for other factors as defined in Hunt *et al*. (2003). This is depicted in Table 2, which illustrates that the source of 'technical progress' can take many forms. It can be embodied, disembodied, endogenous and exogenous and hence unlikely to be modelled adequately by a simple linear deterministic time trend (see Hunt *et al*., 2003 for further discussion).

{Table 2 about here}

Table 2 illustrates that the UEDT could also be significantly affected by a change in 'tastes' and hence has a significant effect on the demand for energy. Here 'tastes' encompass not only an exogenous change in consumer preferences, but also a whole range of non-economic influences that may at one time or another have an effect on the demand for oil. The list is long and will almost certainly change over time. However, it will include both socio-demographic and geographic factors as identified by Wohlgemuth (1997, p. 1111), such as family size and structure, gender, work status, population age structure, population density, urban to rural changes, physical and telecommuting patterns.

Therefore, a change in 'tastes' holding 'technical progress' and the economic influences such as prices and income constant, will result in a shift in the demand curve – to the left or the right. One example is the significant switch in energy for space heating from coal to gas or oil products that occurred during the 1960s and 1970s in many industrial countries. The reason why consumers switched from coal is not fully explained by economic factors, but by

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transportation demand studies for the UK.

the desire to use the cleaner and more convenient alternative energy source. Similarly, Wohlgemuth (1997) argues that although technology may improve fuel efficiency, "evidence suggests that consumer preferences for more comfortable means of transport, increased urban driving and congestion could offset efficiency improvements" (p. 1114).

In summary, in addition to the standard economic variables such as economic activity, price, etc. there is a range of factors that influence energy demand. The ideal situation would be to include data on measures such as technical energy efficiency, consumer preferences, socio-demographic factors, etc. in the general estimated model. However, it is not possible (particularly in a quarterly time series context) to measure all these factors[2], hence past studies of energy demand have normally ignored this issue completely and/or implicitly included all factors as part of the deterministic 'technical progress' trend variable. But, as we have argued above, the influence of these variables may change over time and 'tastes' could be operating in the opposite direction to legitimate technical improvements, hence the need for the more flexible UEDT.[3]

The above economic rationale for considering the more flexible approach to estimating the UEDT is consistent with the *Structural Time Series Model (STSM)* developed by Harvey and his associates which permits a more flexible approach to modelling the trend component. (See for example, Harvey *et al*., 1986, Harvey, 1989, Harvey and Scott, 1994, and Harvey, 1997.) The STSM is therefore considered in the following section

3 METHODOLOGY

Since the early applications by Nachane *et al*. (1988) and Hunt and Manning (1989) cointegration has become the accepted approach for estimating energy demand relationships (see Hendry and Juselius, 2001 and 2002 for an excellent explanation of the approach).

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[2] Some data are available for average fuel economy, family structure, population age structure, etc. but not consistently on a quarterly basis over the whole estimation period for both countries. Moreover, as argued above, these various influences may have significant effects on oil demand at different times (unlike the economic variables - income and price) and therefore the UEDT/STSM approach is seen as appropriate in these circumstances.

[3] When considering aggregate energy demand for a country as a whole (or group of countries such as the OECD or EU) the UEDT will also be influenced by the 'economic structure' and 'substitution'. This is considered in more detail in Hunt *et al*. (2003).

Despite the advances explained by Hendry and Juselius the cointegration approach can only accommodate a deterministic trend and deterministic seasonal dummies. Therefore, Harvey's *Structural Time Series Model* (STSM) is adopted since it is consistent with out interpretation of the UEDT as explained above. In particular, it allows for the estimation of a non-linear UEDT that can be negative, positive, or zero over the estimation period. Moreover, the use of the simple deterministic time trend is not ruled out in the STSM, instead it becomes a limiting case that is admissible only if statistically accepted by the data.

Similar arguments apply to the treatment of seasonality in the STSM. The STSM allows for stochastic or evolving seasonals over the estimation period. Therefore, deterministic seasonal dummies are not excluded from this approach; they are encompassed within the stochastic seasonals and are admissible, provided they are statistically accepted by the data.

Another advantage of using the STSM to estimate energy demand models is in forecasting, at least in the short-term. Imposing a linear trend throughout the sample period results in a UEDT represented by an average trend for the whole estimation period. If the 'true' UEDT is non-linear then the linear approximation obtained from the deterministic trend is likely to lead to poor short-term forecasts. However, the STSM puts more weight on the most recent observations and hence it is far more applicable for forecasting the near future. Likewise, this is particularly applicable when quarterly data are used and the seasonal pattern changes over time (Harvey and Scott, 1994, p. 1339).

Given the flexibility of the STSM, it is the chosen methodology and cointegration is employed in the Appendix as a comparison with the STSM results.[4] The STSM is therefore combined with an Autoregressive Distributed Lag (ARDL) to estimate oil demand functions and the associated income and price elasticities for the transportation sectors of the UK and Japan as explained below.

Structural Time Series Model (STSM)
The STSM allows for the unobservable trend and seasonal components that are permitted to vary stochastically over time. Consider the following quarterly model:

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[4] The prime motivation for adopting the STSM is its flexibility in estimating the trend and seasonals and hence it is particularly suited for our purposes. However, Harvey also argues that it is superior econometric methodology to cointegration (these arguments are summarised in Harvey, 1997).

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

where e_t is the dependent variable in logs (oil), μ_t represents the trend component, γ_t represents the seasonal component, ε_t is a random white noise disturbance term[5], $\mathbf{Z}_t$ is a $k \times 1$ vector of explanatory variables (price and income in logs) 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:

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \qquad (2)$$

$$\beta_t = \beta_{t-1} + \xi_t \qquad (3)$$

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. The exact form of the trend depends upon whether the variances σ_η^2 and σ_ξ^2, known as the *hyperparameters*, are zero or not. If either σ_η^2 and σ_ξ^2 are non-zero then the trend is said to be stochastic.[6] If both are zero then the trend is linear and, as illustrated in Harvey, *et al* (1986), the model reverts to a deterministic linear trend model as follows:

$$e_t = \alpha + \gamma_t + \beta t + \mathbf{Z}'_t\delta + \varepsilon_t \qquad (4)$$

Seasonal Component

The top left-hand charts in Figures 1 and 2 show that there is a distinct seasonal pattern in transport oil consumption for both the UK and Japan. Unlike the demand for space heating, it is not immediately obvious *a-priori* why oil demand should have a seasonal pattern. However, given the seasonality of the corresponding economic activity it is not surprising that oil consumption also has a seasonal pattern. Another contributing factor is that part of oil demand influenced by leisure activities. Harvey (1997, p. 198) and Harvey and Scott (1994, p. 1342) argue that there is little to be lost by including stochastic seasonals instead of

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[5] I.e. $\varepsilon_t \sim NID(0, \sigma_\varepsilon^2)$.
[6] See Table 2 in Hunt *et al*. (2003) for a summary classification of the different types of stochastic trend that can be established.

conventional seasonal dummy variables when using quarterly data. Therefore, in the spirit of 'general-to-specific' modelling, the most general model is initially estimated; one with stochastic seasonals which may be restricted to deterministic (or no) seasonal dummies only if such restrictions are acceptable via a statistical restrictions test.

Accordingly, equation (1) includes the seasonal component, γ_t, which follows the following stochastic process:

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

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

The conventional case is 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.[7]

ARDL Models incorporating Stochastic Trend and Seasonals

We initially estimate the following most general version of equation (1) for oil demand in the transportation sectors of UK and Japan:

$$A(L)\, e_t = \mu_t + \gamma_t + B(L)\, y_t + C(L)\, p_t + \varepsilon_t \tag{6}$$

where $A(L)$ is the polynomial lag operator $1 - \phi_1 L - \phi_2 L^2 - \phi_3 L^3 - \phi_4 L^4$, $B(L)$ the polynomial lag operator $\pi_0 + \pi_1 L + \pi_2 L^2 + \pi_3 L^3 + \pi_4 L^4$, and, $C(L)$ the polynomial lag operator $\varphi_0 + \varphi_1 L + \varphi_2 L^2 + \varphi_3 L^3 + \varphi_4 L^4$. e_t is the natural logarithm of the oil series, y_t the natural logarithm of GDP, and p_t the natural logarithm of the real price of oil.[8] $B(L)/A(L)$ and $C(L)/A(L)$ represent the long-run income and price elasticities respectively. μ_t, γ_t, and ε_t are as defined above.

Estimation

Equation (6), with (2), (3), and (5), is estimated with the disturbance terms assumed to be independent and mutually uncorrelated with each other. As shown above, the

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[7] In addition, initial estimation included a temperature variable for the UK and Japan.
[8] As noted in a previous footnote we did also do some initial investigations by including a temperature variable.

hyperparameters σ_η^2, σ_ξ^2, σ_ω^2, and σ_ε^2 play an important role and govern the basic properties of the model. The Maximum Likelihood (ML) procedure is used to estimate the parameters of the model and the hyperparameters. From these the optimal estimates of β_T, μ_T and γ_T are estimated by the Kalman filter, representing the latest estimates of the *level* and *slope* of the trend and the seasonal components. The optimal estimates of the trend and seasonal components are further calculated by a smoothing algorithm of the Kalman filter.

In order to evaluate the estimated models, the equation residuals (similar to ordinary regression residuals) and a set of auxiliary residuals are estimated. The auxiliary residuals include smoothed estimates of the equation disturbance (known as the irregular residuals), the smoothed estimates of the level disturbances (known as the level residuals) and smoothed estimates of the slope disturbances (known as the slope residuals).[9] The software package STAMP 5.0 (Koopman *et al.*, 1995) was used to estimate all models.

The preferred models are found by testing down from the over-parameterised model of equation (6) without violating a range of diagnostic tests. In particular, the equation residuals are tested for the presence of non-normality, serial correlation, heteroscedasticity, etc. In addition, following Harvey and Koopman (1992), the auxiliary residuals are tested to ensure that no significant outliers and/or structural breaks exist. If a problem is detected, in a similar fashion to Harvey and Koopman (1992), impulse dummies are considered. The preferred models for each country are also re-estimated and tested, via Likelihood Ratio (LR) tests, for the following restrictions:

(a)   deterministic seasonal dummies;

(b)   a deterministic time trend;

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

This allows for a comparison of the estimated long-run elasticities and the statistical performance of the models when the deterministic restrictions are imposed.

Although these tests are important, 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 (a) – (c) are rejected, may not necessarily be

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[9] In practice the level and slope residuals are only estimated if the level and slope components are present in the model, i.e. η_t and/or ξ_t are non-zero.

valid. Also, it might be that the restrictions imposed on the preferred model, found from the STSM framework, might cause a deterioration in the diagnostic tests. Therefore, as a further check on the robustness of the STSM results the models are re-estimated with deterministic seasonal dummies and either a deterministic trend or no trend using the Engle-Granger two step cointegration procedure.

Finally, one further check of the robustness of the main STSM results is conducted. It is sometimes argued that the likelihood function is relatively flat in the hyperparameters and consequently the estimated price and income elasticities are especially sensitive to the hyperparameter estimates. Therefore, the sensitivity of the estimated results are considered by controlling restrictions on the hyperparameter values at the q-ratio[10] of 0.1 or 0.05 in a similar fashion to Harvey (1989, p.406).

Data

This work is part of a wider research project analysing quarterly energy demand data across a number of fuels and sectors comparing Japan and the UK over the period 1971q1 to 1997q4. The data used for this study are quarterly seasonally unadjusted transportation oil consumption, real GDP and the real oil price for the UK and Japan.

UK Transportation oil consumption data, E(uk), refers to UK Final Consumption 'petroleum' for the transport sector in million tonnes of oil equivalent (mtoe) from various issues of the *UK Energy Trends, Department of Trade and Industry (DTI)* up to June 1999. *e(uk)* represents the natural logarithm of E(uk). The nominal and constant price expenditure estimates of UK Gross Domestic Product GDP(E) at market prices were kindly supplied by the UK Office of National Statistics (ONS) since the seasonally unadjusted data are not published. Y(uk) 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. *y(uk)* represents the natural logarithm of Y(uk). The nominal price index for oil was derived by weighting the appropriate Fuel Price Index from various issues of the *UK Energy Trends*. The real index of oil prices, P(uk), was found by deflating the nominal index

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[10] The q-ratio refers to the relative variance, known as the signal to noise ratio, which is $\sigma^2_\eta / \sigma^2_\varepsilon$.

by the implicit GDP(E) deflator. *p(uk)* represents the natural logarithm of P(uk).[11] The UK data are illustrated in Figure 1.

{Figure 1 about here}

Transportation oil demand for Japan, E(jpn), refers to final consumption of petrol and diesel oil in 10^{10} Kcal taken from various issues of the *Yearbook of Production Supply and Demand of Petroleum, Coal and Coke, Ministry of Economy, Trade, and Industry (METI). e(jpn)* represents the natural logarithm of E(jpn). Y(jpn), real Gross Domestic Product (GDP) (1990, Billion Yen) for Japan is from the *Economic and Social Research Institute (ESRI), Cabinet Office, Government of Japan* website.[12] *y(jpn)* represents the natural logarithm of Y(jpn). The nominal retail price indices of petrol and diesel oil were taken from various issues of the *Price Index Annual, The Bank of Japan and* divided by the Final Private Consumption Quarterly Deflator (1990 = 100), taken from the ESRI. The 'real transportation oil price', P(jpn), was derived as a weighted average of the deflated petrol and diesel oil price indices. *p(jpn)* represents the natural logarithm of P(jpn).[13] The data for Japan are illustrated in Figure 2.

{Figure 2 about here}

The major advantage of using quarterly data is the significantly increased number of degrees of freedom. Many energy demand studies across a range of fuels and sectors have been conducted using annual data resulting in a very limited number of degrees of freedom, which arguably questions the robustness of some of the estimates. This is highlighted for the present context in Table 1 where there is only one study that used 40 or more observations. Moreover, the need for an adequate number of degrees of freedom is particularly relevant when using the ML estimation procedure; unbiased estimates will only be obtained if the sample size is sufficiently large to ensure the appropriate asymptotic properties are fulfilled (Thomas, 1993, p. 51). For example, a sample size of 20 is clearly insufficient to gain the

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[11] A temperature variable, TEMP(uk), was also included in some initial estimation. This refers to the average GB quarterly temperature in degrees Celsius taken from various issues of the *UK Digest of Energy Statistics (DUKES), DTI.*

[12] http://www.esri.cao.go.jp.

[13] The temperature variable, TEMP(jpn), used in initial estimation for Japan refers to the average of Tokyo and Osaka air temperature in degree Celsius taken from various issues of the *Meteorological Agency Annual*

desirable asymptotic properties (Kennedy, 1992, p. 19). Therefore, the data set used here involves a total of 108 observations for each country (significantly more than the previous studies in Table 1) allowing adequate degrees of freedom for estimation, thus ensuring the model has the desirable asymptotic properties, even when some observations are used for lags and forecast tests.

There are of course some drawbacks with using quarterly data. Firstly, a wide range of data are often only available on an annual basis, so that some variables will need to be excluded from the analysis. A measure of fuel efficiency is a particularly pertinent example in the present context. Secondly, quarterly data series are usually subject to seasonal fluctuations that have to be appropriately addressed to ensure that the residuals do not suffer autocorrelation, etc. There is, therefore, a trade-off between ensuring that the data set has adequate degrees of freedom and being able to include all relevant variables and the need to model seasonality explicitly. This highlights the importance of adequately treating the seasonal issue as well as ensuring that non-measurable effects are appropriately captured as with the STSM framework used here.

The oil data aggregates gasoline (or petrol) with diesel. Arguably these two components have different characteristics and it would be better to estimate demand functions for the two separate elements.[14] However, it is not possible within the current study to separate the two components over the sample period. Although quarterly data for UK total oil consumption is available back to 1971q1, the split of petrol and diesel is not available on a quarterly basis back to 1971q1. It would not, therefore, be possible to do the comparison of Japan and the UK with quarterly petrol data back to 1971. Moreover, if separate quarterly functions were explored the data limitations would result in a somewhat curtailed data set that excluded the important early 1970s period. Consequently, for the current study total transportation oil is used.

(Meteorological Agency, Japan).

[14] This has, however, changed somewhat over recent years where diesel has been used more for passenger cars. For example, the proportion of diesel cars in GB increased from under ½% in 1980 to 9% in 1997 whereas the proportion increased from 7% in 1972 to 18½% in 1997 for Japan. (Sources: *UK Transport Statistics Bulletin, Vehicle Licensing Statistics: 2001, DTLR* and private correspondence; *Handbook of Energy and Economic Statistics in Japan 2002, EDMC*.) Therefore, given the increasing interdependence between the two elements it is of interest to explore the aggregate measure and arguably the STSM outlined above is ideal for modelling the underlying changes taking place in the transportation sector of each country.

4 RESULTS

The over parameterised model of equation (6) was initially estimated for transportation oil demand for the UK and Japan for the period 1972q1 to 1995q4 - saving two years (8 observations) for post-sample prediction tests. By testing down from equation (6) a suitable restricted model was selected following the methodology outlined above. The preferred equations for the UK and Japan are given in Table 3. In general, the results indicate that the models fit the data well for both countries with both preferred specifications passing all diagnostic tests with no indication of mis-specification. In addition, the results for both countries are little affected by changes to the hyperparameter values - suggesting the estimated elasticities are robust. Moreover, for both countries the trends and seasonal dummies exhibit stochastic patterns, although the exact specifications differ somewhat. The results for the two countries are discussed in more detail below.

{Table 3 about here}

UK

The standard diagnostic tests for the model are very satisfactory with no indication of residual serial correlation, non-normality, or heteroscedasticity. In addition, there is no indication of non-normality of the auxiliary residuals; hence no dummies were required for any significant outliers or structural breaks.[15] The model is also stable as indicated by the post-sample predictive failure tests. The lagged dependent variables and lagged price variables were found to be insignificant and only the first lag of GDP was found to be significant and hence retained. Consequently, the model contains a small number of lagged variables, but the residuals are still white noise. This leads to a fairly quick adjustment of transportation oil demand to the price change in the UK.[16] The estimated long-run elasticities income and price are 0.80 and -0.12 respectively.

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[15] An impulse dummy for 1980q1 was experimented with in some initial estimation in order to capture an outlier during the period of recession in the UK. However, it was not required in the preferred model in Table 3 and when included it had no discernible effect on the estimated parameters. Dummies for 1974 and/or 1979 were not needed since there was no fuel rationing implemented in the UK.

[16] This finding is in contrast to Goodwin (1992) who finds that the long-run price elasticity tend to be between 50 per cent higher and three times higher than the short-run.

The stochastic trend in the preferred model is the *local level with drift model*. This model consists of a random walk component to capture the underlying level that evolves in a particular direction as specified by the fixed slope components. The results of the LR tests (a) to (c) clearly indicate that all restrictions are rejected by the data. In addition when imposing some of the restrictions, such as a deterministic trend, there were particularly adverse effects on the diagnostic tests resulting in very severe serial correlation of the residuals and problems of non-normality. This gives further support to the view that stochastic modelling is necessary in this case.

Focussing on the estimated UEDT from the preferred UK model in Table 3, it can be seen from the top left-hand chart of Figure 3 that it is generally upward sloping.[17] Therefore, holding income and price constant, the underlying use of transportation oil has been increasing. This illustrates that over the past 25 years (other than the last few years of the estimation period) the sector has become *more* energy intensive. This increase in energy intensity shown by the upward UEDT reflects a shift in the oil demand curve to the right, *ceteris paribus*.

{Figure 3 about here}

The estimated hyperparameter of the trend level is non-zero. However, the estimated hyperparameter of the slope is zero giving an underlying trend of 0.56% p.a. (as illustrated in the top right-hand chart of Figure 3). This does not mean that the underlying trend is linear as assumed in conventional modelling. There is still considerable variation around this fixed slope as shown in the top left-hand chart. This stochastic movement of the underlying trend being generated by the shifts in the level component rather than changes in the slope or growth rate.

Fuel efficiency of new cars in the UK has improved since 1978 as illustrated in Figure 4.[18] This shows that there was a significant improvement during the early 1980s but it that levelled out thereafter. However, it would appear from the upward sloping shape of the

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[17] The top right hand chart in Figure 3 (and Figure 6) illustrates the quarterly growth rate of the trend *i.e. the change in the slope of the trend component* (given in the top left-hand chart). For the UK it is horizontal since the hyperparameter of the slope is zero, unlike the Japanese results given in Figure 6.

[18] Source: *Transport Trends, UK National Statistics*. Data only available on an annual basis and not available

estimated UEDT in the top left hand side of Figure 3 that generally these improvements have been more than outweighed by other 'taste' effects of the increase in oil demand. This could have come about for many reasons such as the growth in car size and engine power and a worsening of traffic conditions in urban areas, resulting in hardly any change in the vehicle fleet fuel intensity. In addition, the shift from public transport to (more energy intensive) private cars has contributed to the substantial growth of transportation oil demand over the sample period (Schipper *et al.*, 1992, p. 123). The number of car/motorcycle trips per person per year in the UK increased from 437 in 1975/76 to 641 in 1995/97 (an increasing proportion of all trips of 47% in 1975/76 to 61% in 1995/97); whereas the total number of trips by public transport per person per year fell from 127 in 1975/76 to 92 in 1995/97 (a falling proportion of all trips of 14% in 1975/76 to 9% in 1995/97).[19] In addition the distance travelled per person per year in the UK by car/motorcycle increased from 3,430 miles (72% of total) in 1975/76 to 5,590 miles (82%) in 1996/98; whereas the distance travelled per person per year by public transport fell from 839 miles (18%) in 1975/76 to 851 (12½%) in 1996/98.[20] Another possible contributing factor is the increasing use of cars for taking children to school with the number of trips by foot falling and trips by car/van increasing considerably from the mid 1980s.[21] A final factor to consider is the UK proportion of private cars in the total vehicle stock illustrated in Figure 5.[22] This illustrates that in the UK the proportion has always been relatively high (compared to Japan discussed below) and has a clear upward trend other than the last few years. Overall, therefore the estimated UEDT is fully consistent with all the above indicators.

{Figure 4 about here}

{Figure 5 about here}

The hyperparameter of the seasonal components are relatively small compared to that of the level. This indicates that the stochastic movement in the seasonal component is not as large as the stochastic fluctuation of the trend. However, the changes in the seasonal pattern are

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before 1978.
[19] Source: *Transport Trends, 2001, UK National Statistics*.
[20] Source: *Transport Trends, 2001, UK National Statistics*.
[21] Source: *Transport Trends, 2001, UK National Statistics*.
[22] Source: *Transport Statistics Bulletin, Vehicle Licensing Statistic, 2001, UK National Statistics*. Data only available on an annual basis.

still found to be stochastic and are preferred to conventional deterministic seasonal dummies. [23] The pattern is illustrated in the bottom half of the chart of Figure 3. This illustrates that the magnitude of seasonal fluctuations has diminished since the early 1980s, with relative demand in the first and fourth quarters gradually increased and relative demand in the second and third quarters gradually decreased. It is not immediately obvious why these changes have taken place, however, they are relatively small; hence when conducting test (a), with deterministic dummies, the estimated long-run elasticities are very similar.

It is of some interest to compare the estimated elasticities from the preferred model given in Table 3 with those from the restricted versions tests (a) – (c), and the cointegration results discussed in the Appendix. For test (a), the estimated long-run income and price elasticities are 0.86 and –0.12 respectively, whereas for both test (b) and test (c) they are 0.66 and –0.19 respectively. For test (a), therefore, there is no difference in the price elasticity whereas the income elasticity is slightly higher. This is not surprising, given the relatively small seasonal effect discussed above. However, for test (b) and test (c), the price elasticity increases in absolute terms whereas the income elasticity falls. Although the changes are bigger than test (a), they are not that overly dramatic, which is not too surprising given the shape of the estimated UEDT for the UK, which is generally uni-directional and could be approximated by the linear time trend.

The results given in the Appendix show that cointegration is accepted for the UK with a deterministic trend but not without a trend.[24] The estimated long-run income elasticity is 0.52 and long-run price elasticity is –0.22 for the cointegration with trend model. For the cointegration without a trend model the long-run income and price elasticities are 1.14 and –0.12 respectively; however, given cointegration is not accepted these are not considered further. In the short-run dynamic equations, a large number of lags are needed (including some insignificant terms) to ensure that the diagnostic tests are passed for the models. And, despite experimenting with various lag structures, it was not possible to eliminate the problem of heteroscedasticity in the cointegration with trend model. Therefore, the preferred

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[23] As stated above, a temperature variable was also included in some initial estimation. Although the variable is significantly different from zero its inclusion has no discernible effect on the estimated long-run elasticities. When included, the estimated size of the evolving seasonals is smaller, hence the preferred model in Table 3 captures all seasonality through the stochastic seasonal component.
[24] Both include deterministic seasonal dummies.

model from the STSM framework is clearly more parsimonious than the cointegration models.

The estimated long-run elasticities from the cointegration with trend model are, not surprisingly, similar to those from imposing restriction (c) above although the income elasticity is slightly lower and the price elasticity slightly higher (in absolute terms). Therefore, for both test (c) and the cointegration model with trend, the income elasticity is lower and the price elasticity higher (in absolute terms) than those obtained from the STSM framework. In summary, when a stochastic trend and seasonal components are utilised with our UK data the income elasticity is higher and the price elasticity is lower (in absolute terms) than the models incorporating deterministic components. However, given the failure of some diagnostic tests with the deterministic models and the more parsimonious model obtained from the STSM framework, the UK model given in Table 3 is preferred.

JAPAN

Consistent with the UK results, the diagnostics of the model are very satisfactory with no problem of non-normality of the auxiliary residuals; hence, like the UK, no dummies were required for any significant outliers or structural breaks.[25] Moreover, the models are also stable as indicated by the post-sample predictive failure tests. The lagged price variables were found to be insignificant and only the first lag of GDP was found to be significant and hence retained in the preferred model for Japan. In addition, the preferred model includes the second lagged difference of the dependent variable. This was included since the second and third lags of the dependent variable were required to eliminate some problems of serial correlation. Individually they were insignificant but with coefficients of almost equal size (in absolute terms) but of opposite signs. Therefore, the two variables (e_{t-1} and e_{t-2}) were replaced by their difference (Δe_{t-2}) which is significant at the 10% level. Despite this the preferred specification is still fairly parsimonious.[26] The stochastic trend in the preferred model is the most general form, the *local linear model*. This consists of a stochastic level and a stochastic slope.

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[25] Initial estimation indicated that there were outliers in 1990q3 and 1994q3 and impulse dummies for these periods were experimented with. However, further modelling showed that these were not necessary given the normality of the auxiliary residuals so they were excluded. However, their inclusion or exclusion has no discernible effect on the estimated parameters. Dummies for 1974 and/or 1979 were not needed since there was no fuel rationing in Japan.

[26] This rather unusual dynamic relationship appears to be a characteristic of Japanese transportation oil demand

Similar to the UK, the LR tests for the deterministic trend and seasonal restrictions clearly favour the stochastic formulations. In particular, a significantly large LR value is found for the restriction of a deterministic trend. Moreover, the imposed restrictions lead to very severe problems of serial correlation and non-normality of the residuals. All of which highlight the importance of the stochastic formulation for modelling the demand for transportation oil in Japan.[27] The estimated long-run income and price elasticities are 1.08 and –0.08 respectively. Compared to the UK, oil transportation demand in Japan is found to be more income sensitive but less price sensitive in the long-run.

Since the underlying trend contains both a stochastic level and a stochastic slope, there is no clear continuous direction for the UEDT. This is illustrated in the two charts in the top half of Figure 6. This means that the UEDT does not move in one direction with many small fluctuations as seen for the UK. Instead the UEDT, as indicated in the top left-hand chart of Figure 6, moves in a non-linear fashion, increasing rapidly during the 1970s followed by a substantial decline during the early 1980s before beginning to increase again in the late 1980s. Since the late 1980s the UEDT grew strongly, paralleling the 1970s. At the end of the estimation period, it was growing by 1.73% per annum.

{Figure 6 about here}

The movement of the UEDT between 1979 and 1988 was a period when, *ceteris paribus,* there was a decline in the use of transportation oil leading to less energy intensity. This is in contrast to the increase in usage and rise in energy intensive periods of the rest of the estimation period. Hence, during the period between 1979 and 1988 holding income and price constant, the oil transportation demand curve in Japan was shifting to the left whereas at other times it was shifting to the right. This movement in the UEDT represents non-income or price effects given these variables are controlled for in the model, therefore illustrating that the UEDT consists of the 'technical progress' effects *and* changes in 'tastes'.[28]

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since Franzén and Sterner (1995, p. 112) also had a problem specifying the dynamic relationship for this sector.
[27] Like the UK a temperature variable was included in some initial estimation but was always insignificant, irrespective of the specification estimated.
[28] Future research will address how the shape and structure of the UEDT is generated; why exactly does the UEDT for the UK slope upwards for almost all the estimation period whereas there are these distinct periods for Japan's UEDT? This is particularly desirable if the models were to be used for long-term forecasting.

Annual data for average fuel efficiency of the passenger vehicle stock in Japan between 1972 and 1997 are shown in Figure 7.[29] It is interesting to compare the shape of the estimated UEDT in the top left-hand chart of Figure 6 with Figure 7. Both have surprisingly similar shapes, suggesting that the UEDT is picking up the underlying effects of changes in average fuel efficiency of the passenger vehicle stock in Japan. In addition, Figure 8[30] shows the proportion of passenger cars from the total vehicle stock in Japan between 1972 and 1997. This is significantly lower than the UK figures and, unlike the UK, has distinctive changes in trend where the proportion increased up to the late 1970s, decreased during the 1980s, and suddenly grew in the late 1980s. Similar to the UK, this pattern is reflected in the estimated UEDT. Thus, like the UK results, the estimated UEDT appears to be picking up the significant underlying trends in the key aspects of efficiency and 'tastes'.

The estimated hyperparameter value of the seasonal component is 0.162 which is much higher than for the UK (0.044), and the q-ratio, which is sometimes referred to as the *signal to noise ratio*, is also considerably higher.[31] This indicates that changes in the seasonal movement over the sample period exhibit a very strong stochastic pattern that is clearly difficult to model by conventional deterministic seasonal dummies.

The estimated stochastic seasonal pattern is shown in the bottom two charts of Figure 6. The seasonal fluctuation diminished until about 1980 but increased since then. In particular, the demand in the third quarter has grown over the sample period in contrast to the second quarter that dropped from the most consumed period during the 1970s to the second from 1980s onwards. The demand in the first quarter and the fourth quarter has also decreased since 1980. An increase in relative importance of the third quarter against others might be explained by the combined effect from i) a diffusion of air conditioner for summer season equipped in cars and ii) a relative increase in passenger vehicles over the sample period used for leisure activities in the summer season.

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[29] Source: *Handbook of Energy and Economic Statistics in Japan 2002, EDMC* Data is only available on an annual basis.

[30] Source: *Handbook of Energy and Economic Statistics in Japan 2002, EDMC*. Data is only available on an annual basis.

[31] The q-ratios are 0.0506 for the UK and 0.1519 for Japan.

Again, it is interesting to compare estimated elasticities from the restricted versions, tests (a) – (c) and the cointegration results in the Appendix with those from the preferred model presented in Table 3. For test (a) the estimated long-run income and price elasticities are 1.02 and –0.07 respectively which, similar to the UK, do not represent dramatic changes. For test (b), the estimated income and price elasticities are 0.53 and –0.04 respectively and for test (c) 0.51 and –0.04 respectively. Therefore, both of the tests where a linear trend is imposed, the income and the price elasticities almost half. Thus, on this occasion there is a significant impact on the elasticities, which is not surprising given the linear trend does not act as a good proxy for the estimated UEDT for Japan.

The results given in the Appendix show that, similar to the UK, cointegration is accepted for Japan with a deterministic trend but not without a trend.[32] The estimated long-run income elasticity is 0.55 and long-run price elasticity is –0.02 for the cointegration with trend model. For the cointegration without a trend model the long-run income and price elasticities are 1.07 and –0.03 respectively; however, given cointegration is not accepted these are not considered further. In the short-run dynamic equations, a very large number of lags are needed (including some insignificant terms) to ensure that diagnostic tests are passed for the models. Again, similar to the UK results, the preferred model from the STSM framework is far more parsimonious than the cointegration models. Therefore from an econometric perspective the STSM is preferred for Japan. Moreover, the error correction term is not significantly different from zero – casting further doubt about the validity of the cointegration results for Japan.

The estimated long-run income elasticity from the cointegration with trend model is just a little higher than that found when imposing restriction (c) above although the estimated long-run price elasticity is halved (in absolute terms). For both test (c) and the cointegration model with trend, the estimated price elasticities are a half and a quarter respectively of the estimate obtained from the STSM framework, whereas the estimated income elasticities are about a half. In summary, when a stochastic trend and seasonal components are utilised with our data for Japan, the estimated income elasticity is significantly higher and the estimated price elasticity is significantly higher (in absolute terms) than the models incorporating deterministic components. However, given the failure of some diagnostic tests when

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[32] Similar to the UK both specifications include deterministic seasonal dummies.

imposing the deterministic restrictions, the poor cointegration results, and the far more parsimonious model obtained from the STSM framework, the model for Japan given in Table 3 is preferred statistically on a number of fronts.

5 SUMMARY AND CONCLUSION

In this paper, we attempt to estimate efficiently the income and price elasticities of oil demand for the transport sectors of the UK and Japan. Given the growing size and importance of the transportation sector, and the resultant environmental impact, it is vital that accurate estimates are obtained. To achieve this we have demonstrated the need to model adequately the Underlying Energy Demand Trend (UEDT). We have argued that in addition to a 'technical progress' or energy efficiency effect the UEDT must also accommodate other non-measurable influences such as 'tastes'. Given these influences it would be extremely unlikely that the total effect would be adequately modelled by a simple linear time trend, which has been the conventional approach. Therefore, we have adopted Harvey's structural time series model since this allows for a more general and flexible framework. This is achieved by estimating a stochastic underlying trend for the transport sectors of the UK and Japan. Not surprisingly, we find for both countries that a simple linear time trend (or no trend at all) is rejected on a number of criteria. This results in a generally ***upward*** sloping UEDT for the UK suggesting that, *ceteris paribus*, the demand curve for transportation oil in the UK has been shifting to the right over the estimation period. For Japan however, the UEDT has a distinct phase where the UEDT is ***downward*** sloping and hence, *ceteris paribus*, the transportation oil demand curve was shifting to the left but also other phases where the UEDT is ***upward*** sloping hence, *ceteris paribus*, the demand curve was shifting to the right. Moreover, as Hunt *et al*. (2003) demonstrate, mis-specification of the UEDT could lead to significant biases of the income and price elasticities, with the biases dependent on the direction of the UEDT, income, and price. Therefore, in the case of the UK and Japan in particular, these biases are likely to be quite marked given the estimated UEDT and the movement of real transportation oil prices over the period.

The argument that the estimated UEDT will capture a whole range of influences in addition to 'technical progress' is demonstrated for both countries. For the UK, it was illustrated that

a number of 'taste' factors appear to have outweighed the improvements in efficiency. It is even more marked for Japan, where the estimated UEDT has two distinct changes clearly reflecting the changes in the fuel efficiency and the proportion of passenger vehicles, i.e. the combination and interaction of changes in efficiency and 'tastes'.

The evidence presented shows that, even when the data for energy efficiency, tastes, and other variables are unavailable, or not in an appropriate format, the STSM approach is still able to accommodates the effect of these factors on oil demand; with the estimated UEDT acting as an approximation. As indicated earlier in the paper, the STSM/UEDT approach can be considered a second best procedure where it is not possible to obtain all variables and model accordingly. However, in situations where full information on a number of variables is not available, this approach is an ideal 'second best' procedure; one that produces unbiased estimates of the long-run income and price elasticities. This is particularly relevant for energy demand modelling, and oil demand in particular, where the derived demand will not only depend on the efficiency of the energy using appliances but also a whole range of factors (as discussed earlier) that can be captured using the STSM/UEDT approach.

The advantage of allowing for a stochastic formulation for the seasonal pattern in the data has also been demonstrated. The conventional seasonal dummy approach is rejected in favour of the stochastic formulation for both countries. This results in evolving seasonality but with different patterns for the two countries. This again, similar to the arguments for incorporating the UEDT, is important. It is almost impossible to measure the causes of these changes in practice, however the STSM approach implicitly allows for any socio-economic effects that cause the seasonal pattern to change within a year and hence ensure the estimated elasticities are not biased.

As a result of this approach, the estimated long-run price and income elasticities of demand for UK transportation oil are 0.80 and –0.12 respectively. These estimates are both towards the lower end of the range of previous studies (see Table 1). However, our study uses a later data period, a different frequency of data, and a different technique so a true comparison is difficulty. However, given our more general approach and the statistical results, we would argue that our estimates are preferable. For Japan, the long-run income and price elasticities are 1.07 and –0.08 respectively but there are fewer previous studies to compare with than the

UK. However, it was worth noting that the estimates for both the UK and Japan are much lower than the averages of previous oil demand studies calculated by Dahl and Sterner (1991) (see Table 1). In summary, for both countries the estimated income and price elasticities are both lower (in absolute terms) than the previously cited studies. This is not surprising since the previously cited studies generally ignore the issue of the UEDT, so that the estimated price and income effects from these studies are implicitly required to pick up the exogenous effects that in our approach are attributed to the UEDT. In addition the speed of adjustment is much quicker in the present study compared to those cited in Table 1. Again this is to be expected given the STSM/UEDT framework clearly distinguishes between the 'pure' income and price effects, holding other factors such as the appliance stock constant, and adjustment in this context would be expected to be quicker.

Finally, it is worth emphasising the similarities and differences between the results for the UK and Japan. Firstly, the estimated long-run elasticities from using the STSM/UEDT framework, although not identical, are relatively similar. The long-run income elasticities are 1.08 and 0.81 for Japan and the UK respectively; similarly, the long-run price elasticities are –0.08 and –0.12 for Japan the UK respectively. Therefore, the major difference between two countries is the different shape of the UEDTs and the different seasonal patterns. Hence, the underlying differences in the characteristics of the transportation sectors of the two countries, as discussed in the results section, are captured by the stochastic formulations of the UEDT and seasonals. This, it could be argued, is to be expected; the economic influences having a similar impact on oil demand, whereas other underlying factors such as different rates of efficiency, socio-economic factors, consumer preferences, etc. are captured by the different non-linear UEDT and evolving seasonals.

In conclusion, the more flexible approach available via the STSM framework is arguably a superior technique to the more conventional techniques when estimating transportation oil demand functions. It produces unbiased estimates of the long-run income and price elasticities, even when it is not possible to capture all the underlying influences explicitly, and we would speculate, that our estimates are likely to prove more reliable.

In order to facilitate the comparison of the STSM results in the main text, transportation oil demand functions for the UK and Japan are estimated using the Engle-Granger two step cointegration technique. Since the methodology has been well explained in many places (see for example Hendry and Juselius, 2001) only the results are presented here in Table A1.[33]

For the first step of the procedure, two equilibrium demand relationships are estimated for both countries. One with oil demand in logs (e_t) as a function of GDP in logs (y_t), the real oil price in logs (p_t), a constant, deterministic seasonal dummies and a deterministic trend. The other with the deterministic trend omitted. For all relationships the residuals (EC_t) are tested for cointegration by the Augmented Dickey-Fuller test to confirm that the valid long-run relationship is statistically acceptable. The results from this first step, discussed further below, are given in the top part of Table A1.

For the second step a short-run error correction relationship is estimated for all the long-run relationships from the first step. This involved estimating the first difference of e_t as a function of a constant, deterministic seasonal dummies, the first difference of lags on the first differences of e_t, y_t and p_t and the lagged error correction term EC_t. The preferred model was found by testing down from this general equation providing the diagnostic tests given in Table A1 are not violated, such as non-normality, serial correlation, heteroscedasticity, etc. The results of the second step are given in the bottom part of Table A1. The software package PcGive 9.10 (Hendry and Doornik, 1996) was used to estimate all specifications for both steps.

UK
For the UK the estimated long-run income and price elasticities are 0.52 and –0.22 respectively for the specification with a trend and 1.14 and –0.12 respectively for the specification without a trend. However, cointegration is only accepted for the trend specification.[34]

{Table A1 about here}

When estimating the error correction equation for the trend specification it proved impossible to eliminate the problem of heteroscedasticity despite many experiments with different lag structures. Therefore this problem still exists in the preferred model given in Table A1. For the specification without a trend a large number of lags were needed (including some not significant even at the 10% level) to ensure all diagnostic tests are passed. For the trend specification the error correction term is significant at the 1% level, whereas for the no trend specification it is significant at the 5% level.

JAPAN
For Japan, the estimated long-run income and price elasticities are 0.55 and –0.02 respectively for the specification with a trend and 1.07 and –0.03 respectively for the

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[33] For both the UK and Japan all variables are non stationary and are integrated of order 1, I(1).

[34] The coefficient on the time trend is positive, which is to be expected given the shape of the estimated UEDT via the STSM framework.

specification without a trend. However for Japan, cointegration is accepted at the 5% level for the trend specification but rejected for the no trend specification.[35]

For Japan longer lags were required than the UK to ensure all diagnostic tests are passed resulting in a large and complicated lag structure for both specifications. However, the error correction terms in both specifications were always not significantly different from zero – casting some doubt on the robustness of the cointegration results for Japan.

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[35] The coefficient on the time trend is also positive for Japan – although it is not obvious that this is to be expected given the shape of the estimated UEDT via the STSM framework this is .

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TABLE 1. SELECTED TRANSPORTATION OIL DEMAND STUDIES FOR THE UK, JAPAN AND OECD

Study (year of publication)	Area covered	Technique / model used	Data used	Estimated LR elasticities
Dargay (1992)	Petrol and diesel oil	Dynamic ECM irreversible demand model	UK annual data 1960 - 88 (29 obs.)	$\eta_y = 1.49$ $\eta_p = -0.10$ (insignificant at 10% level)
		Dynamic ECM conventional (reversible) model	UK annual data 1960 - 88 (29 obs.)	$\eta_y = 0.70$ (insignificant at 10% level) $\eta_p = -0.40$ (insignificant at 10% level)
Dargay (1993)	Petrol	EG 2-step (structural form model)	UK annual data 1950 - 91 (42 obs.)	$\eta_y = 1.5$ $\eta_p = -0.7$ to -1.4
Hodgson and Miller (1995)	Petrol	DTI energy model	UK (details are not reported)	$\eta_y = 0.81$ $\eta_p = -0.3$
Fouquet *et al.* (1997)	Petrol	EG 2-step	UK annual data 1960 - 94 (35 obs.)	$\eta_y = 1.95$ to 2.05 $\eta_p = 0$
Franzén and Sterner (1995)	Petrol	Dynamic log linear model	UK annual data 1960 - 88 (29 obs.)	$\eta_y = 1.6$ $\eta_p = -0.4$
			Japan annual data 1960 - 88 (29 obs.)	$\eta_y = 0.77$ $\eta_p = -0.76$ (η_y and η_p obtained from a model with an arbitrary restriction on the lagged dependent variable)
			OECD aggregated data 1960 - 88 (29 obs.)	$\eta_y = 1.30$ $\eta_p = -0.60$
Sterner and Dahl (1991)	Petrol	Dynamic log linear model	OECD aggregated annual data 1960 - 85 (26 obs.)	$\eta_y = 1.1$ to 1.3 $\eta_p = -0.80$ to -0.95
Dahl and Sterner (1991)	Petrol	Literature survey	n/a	$\eta_y = 1.31$ $\eta_p = -0.80$ (η_y and η_p are average values based on the dynamic log-linear model)
Goodwin (1992)	Petrol	Literature survey	n/a	$\eta_p = -0.71$ (time series case)
Johansson and Schipper (1997)	Car fuels including Diesel, LPG and CNG	Dynamic log linear model (structural form model)	12 OECD individual data 1973 - 92 (20 obs. for each country)	$\eta_y = 1.2$ (mean value) $\eta_p = -0.7$ (mean value)
DTI (2000)	Road fuel	(details are not reported)	UK (details are not reported)	$\eta_p = -0.23$

Note: η_y = the long-run income elasticity, η_p = the long-run price elasticity

TABLE 2. UNDERLYING ENERGY DEMAND TREND (UEDT)

Underlying Energy Demand Trend (UEDT)			
(Pure) **Technical energy efficiency**			**'Tastes'**
Embodied		**Disembodied**	(Exogenous)
(Endogenous)	(Exogenous.)	(Exogenous)	

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TABLE 3 ESTIMATED STSM TRANSPORTATION OIL DEMAND FUNCTIONS FOR THE UK AND JAPAN 1972q1 - 1995q4 (DEPENDENT VARIABLE e_t)

Variables	UK	JAPAN
y_t	0.5708**	0.6464**
	(5.259)	(3.599)
y_{t-1}	0.2307*	0.4338*
	(2.162)	(2.488)
p_t	-0.1233**	-0.0828**
	(4.058)	(3.605)
Δe_{t-2}		-0.1229
		(1.833)
Estimated Long-Run Elasticities		
Income (Y)	0.801	1.080
Price (P)	-0.123	-0.083
Estimated Hyperparameters		
$\sigma_\varepsilon^2 \times 10^{-4}$	0.8703	1.0667
$\sigma_\eta^2 \times 10^{-4}$	0.7699	0.3837
$\sigma_\xi^2 \times 10^{-4}$	0	0.0128
$\sigma_\omega^2 \times 10^{-4}$	0.0440	0.1620
Nature of Trend	Local level with drift	Local trend
Diagnostics		
Standard Error	1.58%	1.78%
Normality	1.05	0.29
Kurtosis	0.01	0.01
Skewness	1.04	0.28
H(30)	0.89	0.82
r(1)	0.01	-0.01
r(4)	-0.06	-0.07
r(8)	0.00	-0.05
DW	1.97	2.00
Q	$Q_{(8,6)}$=0.71	$Q_{(9,6)}$=6.12
R^2	0.99	0.99
R_s^2	0.50	0.61
Auxiliary Residuals		
Irregular: Normality	0.58	2.53
Kurtosis	0.34	1.99
Skewness	0.24	0.55
Level: Normality	1.45	2.51
Kurtosis	0.68	0.36
Skewness	0.77	2.15
Slope: Normality	n/a	1.40
Kurtosis	n/a	0.30
Skewness	n/a	1.10
Prediction test (96q1-97q4)		
$\chi_{(8)}^2$	7.54	4.85
Cusum *t* (91)	-0.45	-0.90
LR tests		
Test (a)	7.09**	48.01**
Test (b)	46.00**	155.91**
Test (c)	46.46**	158.34**

Notes:

➢ t-statistics are given in the parenthesis.

➢ ** indicates significant at the 1% level and * indicates significant at the 5% level.

➢ The coefficient on Δe_{t-2} for Japan is significant at the 10% level.

➢ The restrictions imposed for the LR tests (a), (b), and (c) are explained in the text.

➢ Normality is the Bowman-Shenton statistic approximately distributed as $\chi_{(2)}^2$;

➢ Skewness statistic is approximately distributed as $\chi_{(1)}^2$;

- H(30) is the test for heteroscedasticity, approximately distributed as $F_{(30, 30)}$;
- r(1) r(4) and r(8) are the serial correlation coefficients at the 1st, 4th and 8th lags respectively, approximately distributed as N(0,1/T);
- DW is the Durbin Watson Statistic;
- Q(n,6) is the Box-Ljung Q-statistics based on the first n residuals autocorrelation and distributed as $\chi^2_{(6)}$;
- R^2 is the coefficient of determination;
- R_s^2 is the coefficient of determination based on the differences around the seasonal mean;
- $\chi^2_{(8)}$ is the post-sample predictive failure test;
- The Cusum t is the test of parameter consistency, approximately distributed as the t-distribution.

TABLE A1 ESTIMATED COINTEGRATING TRANSPORTATION OIL DEMAND FUNCTIONS FOR THE UK AND JAPAN 1971q1 - 1995q4

	UK		JAPAN	
	Deterministic Trend	No Trend	Deterministic Trend	No Trend
LONG-RUN EQUILIBRIUM RELATIONSHIPS				
Coefficients/Elasticities				
Income (Y)	0.5162	1.1445	0.5485	1.0723
Price (P)	-0.2221	-0.1233	-0.0178	-0.0273
Time	0.0033	---	0.0047	---
Unit root tests				
$ADF(p)$	$ADF(0) = -5.94**$	$ADF(3) = -1.67$	$ADF(4) = -2.12*$	$ADF(4) = -1.24$
SHORT-RUN DYNAMIC EQUATIONS				
Coefficients				
Δe_{t-1}		-0.3643** (3.534)	-0.3674** (3.798)	-0.3750** (3.865)
Δe_{t-2}		-0.2848** (2.835)	-0.3096** (3.177)	-0.3154** (3.245)
Δe_{t-3}		-0.1629 (1.796)		
Δe_{t-4}			0.3320** (3.684)	0.3308** (3.653)
Δy_t	0.4807** (4.907)	0.6029** (5.834)	0.4478* (2.352)	0.4571* (2.404)
Δy_{t-1}	0.1956 (1.983)	0.4060** (2.951)		
Δy_{t-2}		0.1762 (1.267)	0.6650** (3.245)	0.6670** (3.191)
Δy_{t-3}		0.1501 (1.265)		
$\Delta y_{t-1} + \Delta y_{t-3}$			0.2507 (1.970)	0.2479 (1.871)
Δp_t	-0.1677** (5.003)	-0.1620** (4.713)	-0.1113* (2.521)	-0.1162** (2.521)
Δp_{t-1}	0.0973** (2.973)			
Δp_{t-2}	0.0662 (1.913)			
EC_{t-1}	-0.4983** (4.907)	-0.1694* (2.146)	-0.0524 (0.827)	-0.0360 (0.608)
Diagnostics				
Standard Error	1.53%	1.58%	2.10%	2.10%
R^2	0.95	0.95	0.88	0.88
Normality	1.90	0.27	1.30	1.47
AR 1-4	$F_{(4,82)} = 0.50$	$F_{(4,79)} = 1.21$	$F_{(4,79)} = 1.44$	$F_{(4,79)} = 1.50$

ARCH 4	$F_{(4,78)} = 2.12$	$F_{(4,75)} = 2.31$	$F_{(4,75)} = 1.14$	$F_{(4,75)} = 1.12$
Het (squares)	$F_{(15,70)} = 2.56^{**}$	$F_{(21,61)} = 1.55$	$F_{(19,63)} = 1.61$	$F_{(16,63)} = 1.54$
Het (sqs. & crs. prods.)	$F_{(48,37)} = 0.91$	n/a	$F_{(71,11)} = 0.76$	$F_{(71,11)} = 0.74$
RESET	$F_{(1,85)} = 0.05$	$F_{(1,82)} = 1.56$	$F_{(1,82)} = 3.35$	$F_{(1,82)} = 3.66$
Predictive Tests (96Q1-97Q4)				
$\chi^2_{(8)}$	15.22	14.40	1.59	1.67
CHOW	$F_{(8,86)} = 1.77$	$F_{(8,83)} = 1.70$	$F_{(8,85)} = 0.15$	$F_{(8,83)} = 0.16$

Notes:

➢ The estimation period for the long-run equations (summarised in the top half of the table) was 1971q1 – 1997q4. The dependent variable is e_t

➢ The short-run dynamic equations were estimated over the period 1972q1 – 1995q4 for the UK and 1972q2 – 1995q4 for Japan (summarised in the bottom half of the table). The dependent variable is Δe_t

➢ t-statistics are given in the parenthesis.

➢ ** indicates significant at the 1% level and * indicates significance at the 5% level.

➢ For the UK other than Δy_{t-2} and Δy_{t-3} all non starred variables are significant a the 10% level.

➢ For Japan other than EC_{t-1} all non starred variables are significant a the 10% level.

➢ For the long-run Static E-G estimation the *ADF(p)* is the Augmented Dickey-Fuller test with no constant or trend included, but with sufficient lagged differences to ensure serially independent errors (maximum lag denoted by p);

➢ The short-run equations also included a constant and three seasonal dummies.

➢ The Normality statistic is that given in PcGive and is distributed as $\chi^2_{(2)}$;

➢ DW is the Durbin-Watson test for first-order autocorrelation;

➢ AR 1-4 is a test for serial correlation up to order 4 and is distributed as $F_{(4, n2)}$;

➢ ARCH 4 is a test for an Autoregressive Conditional Hetereoscedastic structure in the residuals and is distributed as $F_{(4, n3)}$;

➢ Het (squares) is a tests for the residuals being heteroscedastic owing to omitting squares of the regressors and is distributed as $F_{(n4, n5)}$;

➢ Het (squares & cross prods.) is the White test for heteroscedasticity, which includes all squares (as in the previous heteroscedasticity test) and all cross-products of variables; and is distributed as $F_{(n6, n7)}$;

➢ RESET is a test for functional form mis-specification and is distributed as $F_{(1, n8)}$;

➢ $\chi^2_{(8)}$ is the post-sample predictive failure test;

➢ CHOW is the post-sample parameter constancy test and is distributed as $F_{(8, n9)}$.

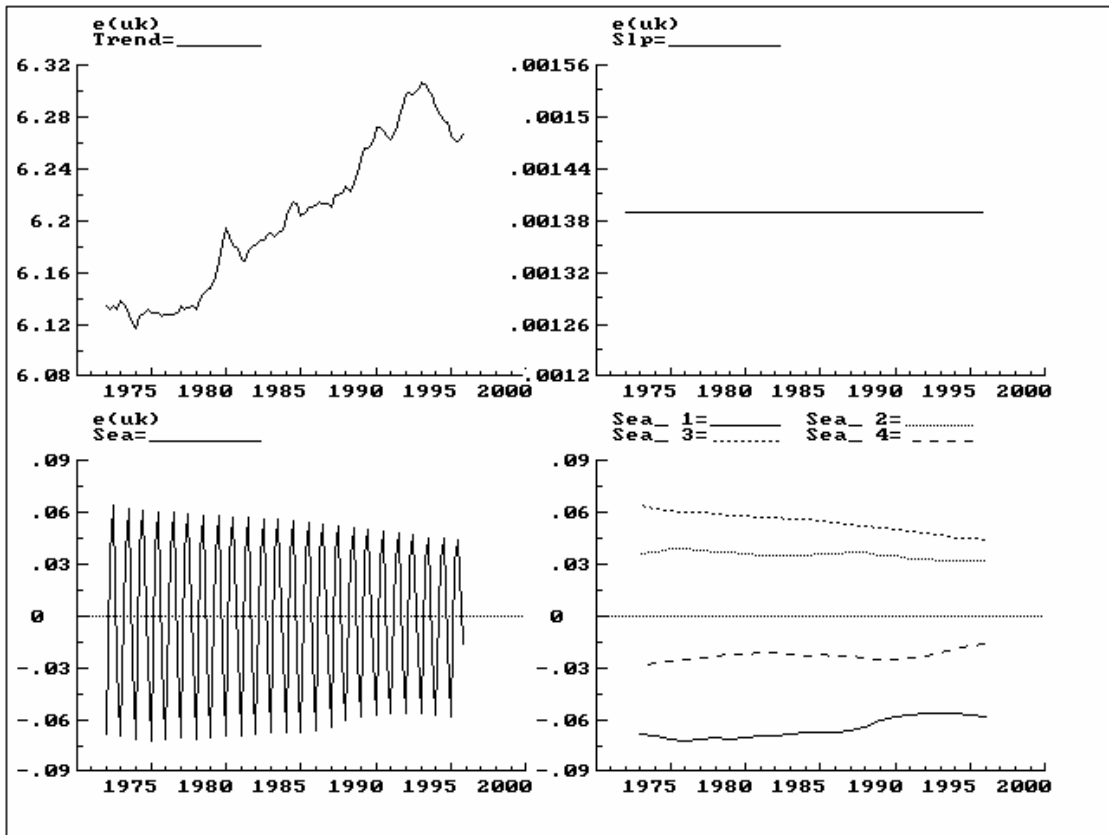➢ n/a is where the test statistic is not available due to inadequate degrees of freedom.
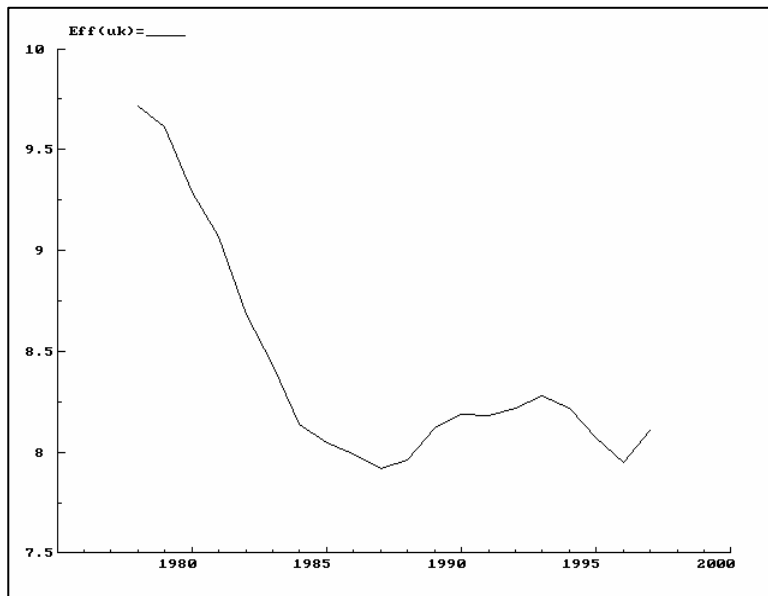
Figure 1: Data for the UK
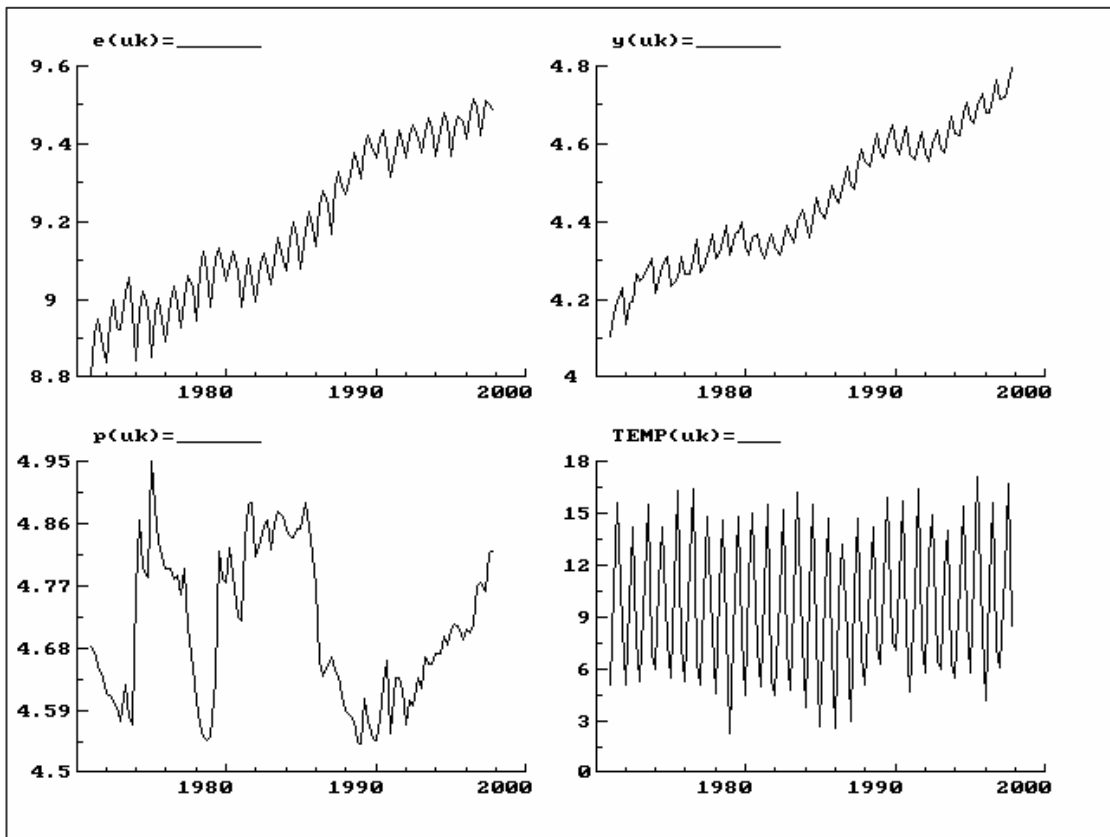
Figure 2: Data for Japan
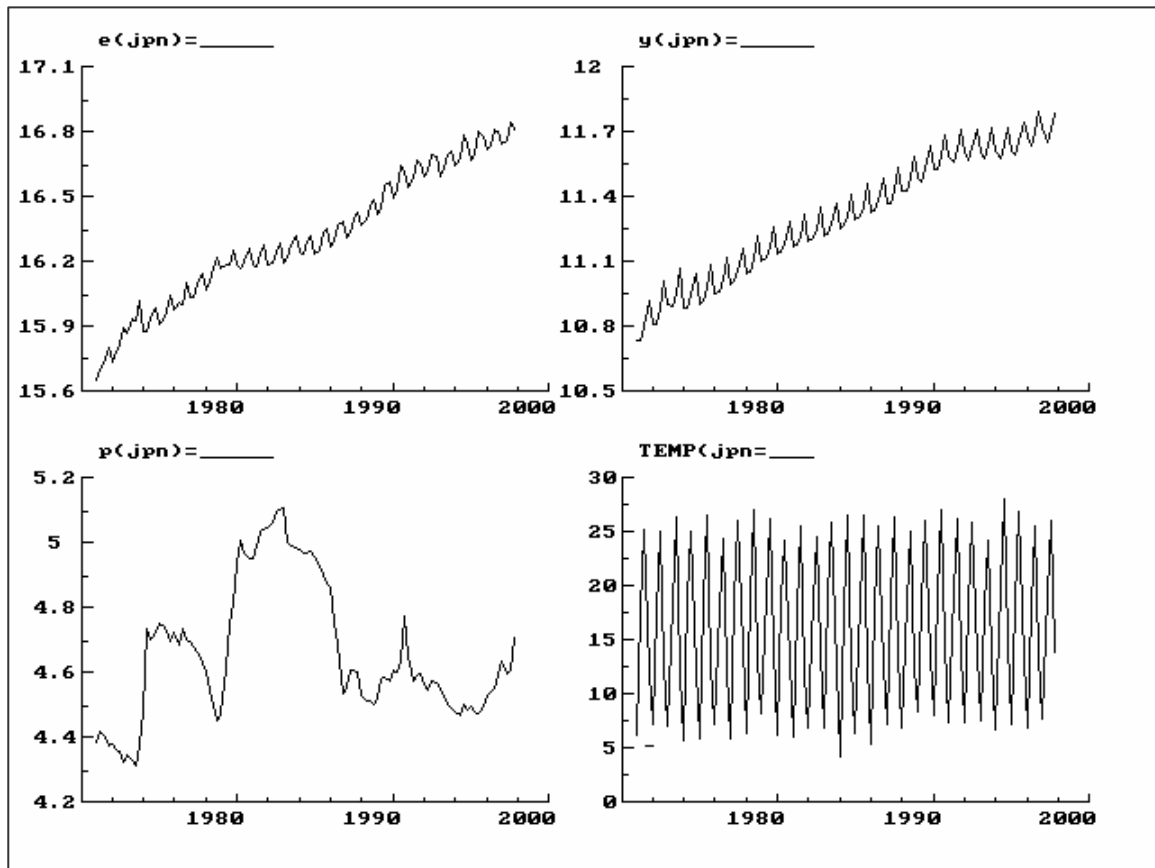
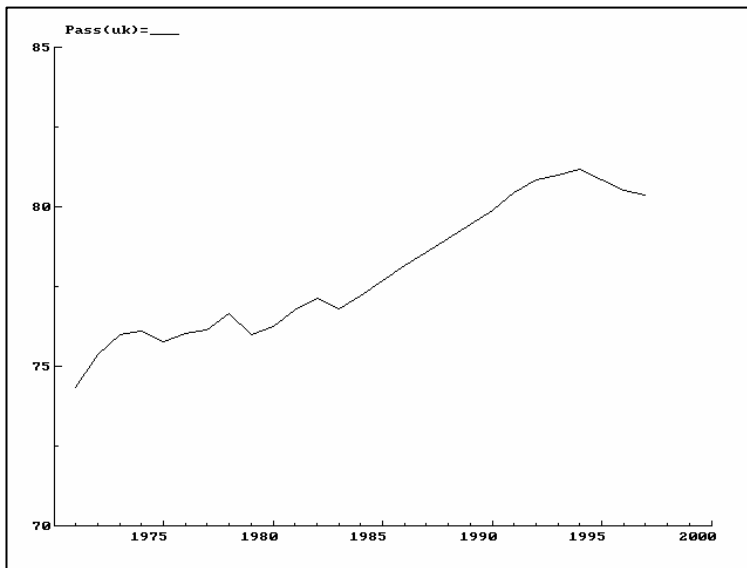**Figure 3: Trend and Seasonals for the UK**

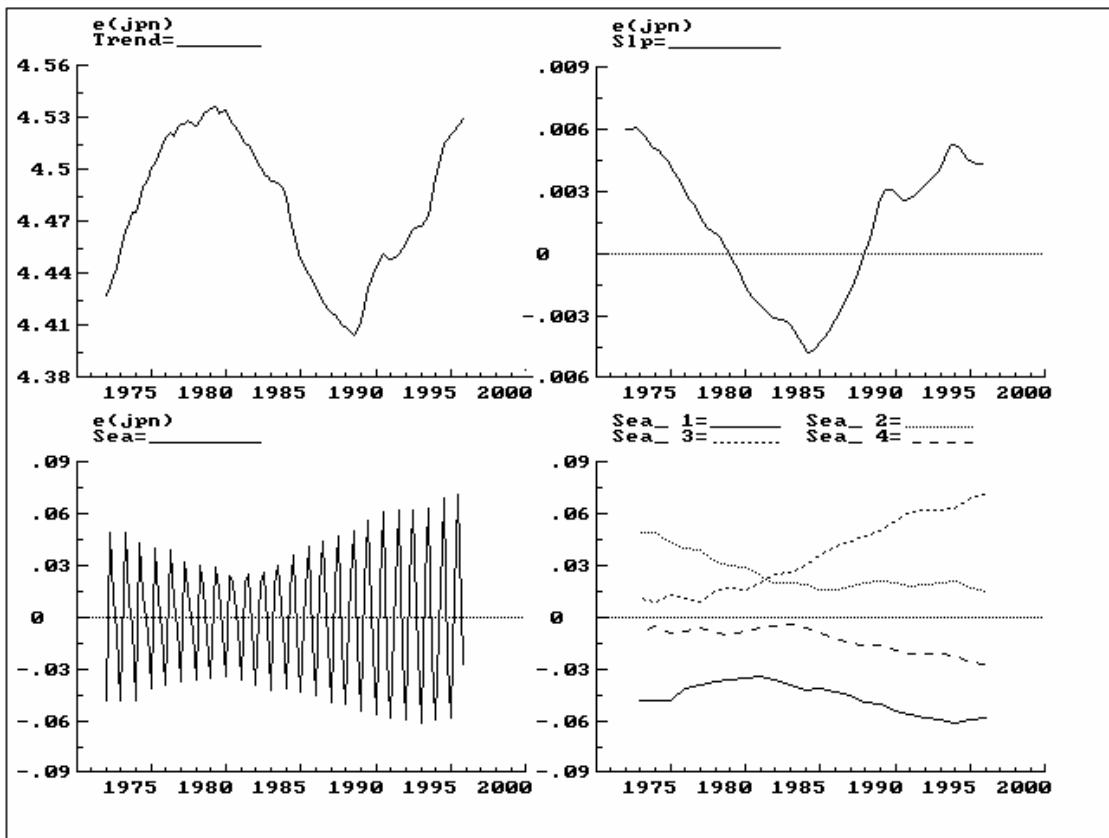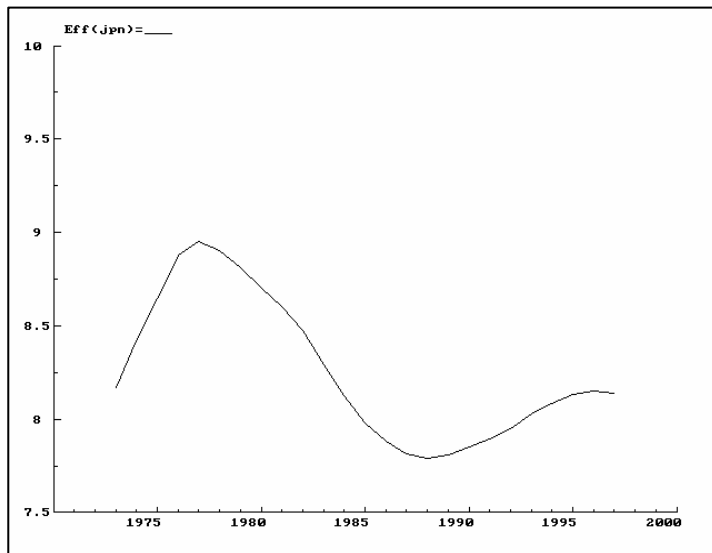**Figure 4: Average New Car Fuel Efficiency in the UK (litres/100km)**

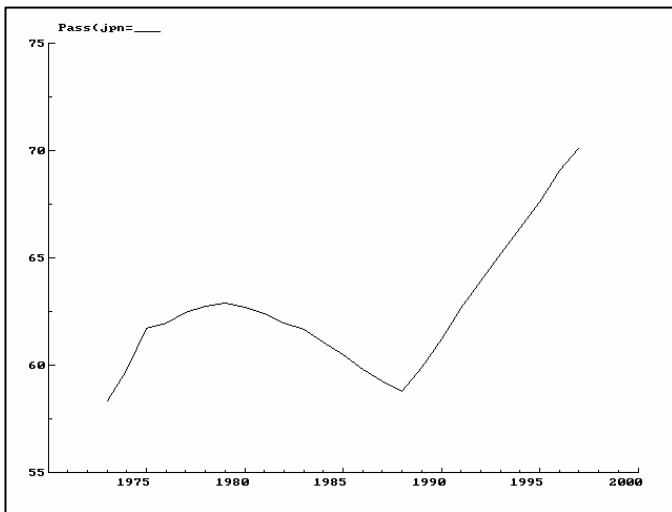**Figure 5: Percentage of Private Cars in the Total Vehicle Stock in the UK**

Figure 6: Trend and Seasonals for Japan

Figure 7: Average Fuel Efficiency of the Passenger Vehicle Stock in Japan (litres/100km)

Figure 8: Percentage of Passenger Cars in Total Vehicle Stock in Japan

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