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

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Outline

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Introduction

- No written paper (so slides include as much info as possible)
- Part of an ongoing project at SEEC and is work in progress
- Why model energy demand? / Importance of the topic
- Important to recognise that energy is a derived demand
- Therefore important to adequately capture technical progress (or energy efficiency improvements)
- AND other important exogenous factors.
- Need an appropriate model and econometric technique.
- Concentrate on time – series applications
  - Will not talk about Cross – section and/or Panel applications

Background – Technical Progress Debate - 1

- There has been a debate in the energy economics literature about the use of a deterministic time trend as a way of capturing 'technical progress' (or improvements in energy efficiency).
- For example
  - Beenstock & Willcocks (1981, 1983) - argue that need to try and capture TP when estimating energy demand functions.
    - Therefore used a simple deterministic trend

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Background – Technical Progress Debate - 2

- Kouris (1983a, 1983b) - has argued against trying to capture TP, especially by using a linear trend.
  - Argues that TP is an important factor that has always been very difficult to quantify unless a satisfactory way of measuring it can be found.
- Moreover, Kouris argues that most TP is induced by price changes rather than being exogenous and should be incorporated in the price elasticity.

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Background – Technical Progress Debate - 3

- Beenstock and Willcocks, disagree and argue that it is important to attempt to capture exogenous TP and although using a linear trend is not that satisfactory - it is better than just ignoring the matter.
- Furthermore, accepting that TP can be exogenous and/or induced by price changes Jones (1994) argues that it is important to distinguish between the normal 'price effects' as measured by the price elasticity and the endogenous TP effect.

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Underlying Energy Demand Trend (UEDT) - 1

- More recently with colleagues at the Surrey Energy Economics Centre (SEEC) we have attempted to extend the debate by developing the wider concept of the UEDT
- In addition to the TP (energy efficient) arguments above, we also argue that there are a range of other exogenous factors that potentially will have an important impact on energy demand. For example:

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Underlying Energy Demand Trend (UEDT) - 2

- Environmental pressures and regulations
- Energy efficiency standards
- Substitution of labour, capital or raw materials for energy inputs
- General changes in tastes that could lead to a more OR less energy intensive situation e.g.
  - increase in use of vehicles - taking children to school, etc.
  - in UK shift from coal to natural gas.

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Underlying Energy Demand Trend (UEDT) - 3

- And also if analysing aggregate sectors then the change in the Economic Structure will also be important, such as:
  - Switch from energy intensive manufacturing to less energy intensive services.
- Consequently, there are a number of exogenous ‘taste’ factors that will influence energy demand (both positively and negatively) and will vary over time.
  - Which in many practical situations are not measurable in an appropriate and consistent way for the relationship being investigated.

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Underlying Energy Demand Trend (UEDT) - 4

- In summary, it is important to be able to capture the UEDT effect that may be positive and/or negative and changing over time.
- Therefore need an appropriate econometric methodology.
- And fortunately, there is a technique that enables this - Harvey's Structural Time Series Model (STSM)

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Structural Time Series Model (STSM) of Energy Demand - 1

- In addition to the above, we also argue that over the last 15 years or so there has been an over reliance on the cointegration technique
  - Not always the right tool for the job of estimating energy demand functions.
  - In energy, as Harvey (1997) states in general, the "emphasis on unit roots, vector autoregression and cointegration has focussed too much attention on tackling uninteresting problems by flawed methods" (p. 200).
- But will not dwell on that here given time constraints.

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STSM of Energy Demand - 2

- $A(L)\ e_t = \mu_t + B(L)\ y_t + C(L)\ p_t + \varepsilon_t$ (1)

  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 $\pi_0 + \pi_1 L + \pi_2 L^2 + \pi_3 L^3 + \pi_4 L^4$;
  - C(L) the polynomial lag operator $\varphi_0 + \varphi_1 L + \varphi_2 L^2 + \varphi_4 L^3 + \varphi_4 L^4$;
  - e_t is the natural logarithm of energy consumption;
  - y_t the natural logarithm of income/output;
  - p_t the natural logarithm of the real energy;
  - B(L)/A(L) the long-run income/output elasticity;
  - C(L)/A(L) the long-run price elasticity;
  - ε_t the standard error term; and

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STSM of Energy Demand - 3

- And:
  - μ_t the Trend Component/Underlying Energy Demand Trend which 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 $\xi_t \sim NID(0, \sigma_\xi^2)$.

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STSM of Energy Demand - 4

- 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 hyper-parameters, are zero or not.
- If either σ_η^2 and σ_ξ^2 are non-zero then the trend is said to be stochastic – see table below.
- If both are zero then the trend is linear and the model reverts to a deterministic linear trend model with $\mu_t = \alpha + \beta t$

STSM of Energy Demand - 5

Classification of Possible Stochastic Trend Models

SLOPE	LEVEL		
	No Level Lvl = 0, $\sigma_\eta^2 = 0$	Fixed Level Lvl ≠ 0, $\sigma_\eta^2 = 0$	Stochastic Level Lvl ≠ 0, $\sigma_\eta^2 \neq 0$
No Slope 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 Slp ≠ 0, $\sigma_\xi^2 = 0$	**(iv)**	**(v)** Conventional regression with a constant and a time trend.	**(vi)** Local Level Model with Drift.
Stochastic Slope Slp ≠ 0, $\sigma_\xi^2 \neq 0$	**(vii)**	**(viii)** Smooth Trend Model.	**(ix)** Local Trend Model.

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STSM of Energy Demand - 6

- The STSM is therefore adopted for two reasons:
  1. It is consistent with the above interpretation of the UEDT;
  2. But it is also seen as a superior methodology to other time series procedures such as unit roots and cointegration:

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STSM of Energy Demand - 7

- Estimation:
  - Estimated equations consist of (1) (2) & (3)
  - The Maximum Likelihood (ML) procedure is used to estimate the parameters of the model and the hyper-parameters.
    - From these the optimal estimates of the slope and level a the end of the period (β_T, and μ_T) are estimated by the Kalman filter.
    - The optimal estimate of the UEDT is further calculated by a smoothing algorithm of the Kalman filter.
  - The preferred models for each country are found by testing down from the over-parameterised model of equation (1) without violating a range of diagnostic tests. In particular:
    - the equation residuals are tested for the presence of non-normality, serial correlation, heteroscedasticity, etc.
    - the auxiliary residuals are tested for normality, etc to ensure that no significant outliers and/or structural breaks exist.
  - Using STAMP 6.3 - Structural Time Series Analyser, Modeller and Predictor (Koopman, et al., 1995)

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Results for 17 OECD Countries - 1

- Data
  - Consistent data set across 17 countries
  - 1960 - 2000
  - Aggregate energy consumption measured in ktoe (from International Energy Agency (IEA), Paris Databank)
  - GDP in constant $ (from IEA data bank)
  - Real Energy Prices supplied by IEA back to 1978 and spliced with USA Department of Energy Data

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Results for 17 OECD Countries - 2

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

NOTES

- *** indicates significant at 1% level, ** indicates significant at the 5% level and * indicates significant at the 10% level.
- Normality statistic, approximately distributed as χ^2_2.
- Kurtosis statistic is approximately distributed as χ^2_1.
- Skewness statistic is approximately distributed as χ^2_1.
- $H_{(h)}$ is the test for heteroscedasticity, distributed approximately as $F_{(h,h)}$.
- $r_{(\tau)}$ the residual autocorrelation at lag τ distributed approximately as N(0, 1/T).
- DW-Durbin-Watson statistic.
- $Q_{(p,d)}$- Box-Ljung statistic based on the first *p* residuals autocorrelations and distributed approximately as χ^2_d.
- R^2 is the coefficient of determination,
- χ^2_f is the post-sample predictive failure test.
- The Cusum t is the test of parameter consistency, approximately distributed as the t distribution.
- Irr, Lvl and Slp represent Irregular, Level and Slope interventions respectively.

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Results for 17 OECD Countries - 3

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM Part 1

	UK	Canada	Sweden
Parameter Estimates			
y_t	0.44**	0.89***	
y_{t-1}			0.64**
p_t			-0.18***
$p_t - p_{t-2}$	-0.18***		
p_{t-1}		-0.12**	
p_{t-3}	-0.17***		
e_{t-1}	0.26**		
Long-Run Elasticity Estimates			
Income (Y)	0.60	0.89	0.64
Price (P)	-0.23	-0.12	-0.18
Estimated Hyperparameters			
Irregular standard deviation	0.0183	0.0022	0.0092
Level standard deviation	0	0.0220	0.0276
Slope standard deviation	0.0018	0	0.0063
Trend			
Form of UEDT	Smooth trend	Local level trend with drift	Local trend
Growth rate at end of period	-0.63% p.a.	-0.34% p.a.	-0.07% p.a.

Results for 17 OECD Countries - 4

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM Part 1 *continued*

	UK	Canada	Sweden
Diagnostics			
Equation residuals			
Standard error	2.08%+	2.10%	3.21%
Normality	2.25	2.23	1.26
Kurtosis	1.02	0.18	1.00
Skewness	0.57	1.34	0.27
Heteroscedasticity	$H_{(11)} = 0.93$	$H_{(11)} = 0.63$	$H_{(11)} = 0.83$
$r_{(1)}$	0.13	-0.09	-0.05
$r_{(2)}$	-0.01	0.20	-0.12
$r_{(3)}$	0.14	-0.02	-0.04
DW	1.65	2.07	2.03
Box-Ljung statistic	$Q_{(8,6)} = 4.82$	$Q_{(8,6)} = 2.75$	$Q_{(8,5)} = 3.30$
R^2	0.92	0.99	0.96
Auxiliary residuals			
Irregular			
Normality	0.19	1.18	2.14
Kurtosis	0.53	0.02	0.18
Skewness	0.07	0.92	1.21
Level			
Normality	n/a	2.40	2.09
Kurtosis	n/a	0.29	0.71
Skewness	n/a	0.16	0.84
Slope			
Normality	1.86	n/a	1.77
Kurtosis	1.60	n/a	0.15
Skewness	0.03	n/a	1.27
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	0.06	6.15	0.76
Cusum $t_{(3)}$	-0.17	-1.43	-0.69
Likelihood Ratio Tests			
LR	4.05**	38.06***	45.4***

Results for 17 OECD Countries - 5

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

	Austria	Portugal	Ireland
Parameter Estimates			
y_t	1.11***	0.50***	
Δy_{t-2}			0.64**
p_t	-0.12***		
p_{t-1}			-0.12*
p_{t-3}		-0.07*	
$e_{t-2} - e_{t-4}$			0.23**
$\Delta e_{t-1} - \Delta e_{t-2}$	0.16**		
Δe_{t-4}	-0.43***		
Long-Run Elasticity Estimates			
Income (Y)	1.11	0.50	0
Price (P)	-0.12	-0.07	-0.12
Estimated Hyperparameters			
Irregular standard deviation	0.0118	0.0132	0.0027
Level standard deviation	0.0103	0.0165	0.0368
Slope standard deviation	0	0	0.0023
Trend			
Form of UEDT	Local level with drift (with Lvl1989)	Local level with drift	Local trend (with Lvl1971)
Growth rate at end of period	-0.97% p.a.	2.66% p.a.	2.43% p.a.

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Results for 17 OECD Countries - 6

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM
Part 2 *continued*

	Austria	Portugal	Ireland
Diagnostics			
Equation residuals			
Standard error	1.61%	2.25%	3.46%
Normality	2.68	0.14	1.54
Kurtosis	1.77	0.61	1.45
Skewness	0.07	0.01	0.01
Heteroscedasticity	$H_{(10)} = 1.36$	$H_{(11)} = 1.01$	$H_{(10)} = 1.45$
$r_{(1)}$	-0.05	-0.04	-0.07
$r_{(2)}$	0.06	-0.12	-0.08
$r_{(3)}$	-0.16	-0.14	-0.12
DW	1.99	2.03	1.97
Box-Ljung statistic	$Q_{(8,6)} = 2.65$	$Q_{(8,6)} = 3.92$	$Q_{(8,5)} = 7.47$
R^2	0.99	0.99	0.98
Auxiliary residuals			
Irregular			
Normality	0.19	2.39	0.35
Kurtosis	0.65	0.26	0.06
Skewness	0.02	1.27	0.07
Level			
Normality	1.99	0.41	0.32
Kurtosis	1.66	0.36	0.80
Skewness	0.00	0.28	0.01
Slope			
Normality	n/a	n/a	0.29
Kurtosis	n/a	n/a	0.51
Skewness	n/a	n/a	0.14
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	4.51	0.77	2.31
Cusum $t_{(3)}$	-0.26	0.53	0.94
Likelihood Ratio Tests			
LR	**2.60**	6.77***	25.23***

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Results for 17 OECD Countries - 7

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM Part 3

	Italy	Greece	France
Parameter Estimates			
y_t	0.90***	1.10***	1.08***
p_t	-0.10**	-0.14***	-0.21***
Δe_{t-2}			0.23**
Long-Run Elasticity Estimates			
Income (Y)	0.90	1.10	1.08
Price (P)	-0.10	-0.14	-0.21
Estimated Hyperparameters			
Irregular standard deviation	0.0085	0.0164	0.0000
Level standard deviation	0.0132	0.0123	0.0248
Slope standard deviation	0.0089	0.0018	0.0000
Trend			
Form of UEDT	Local trend	Local trend (with Irr1963)	Local level with drift (with Lvl1970 & Irr1988)
Growth rate at end of period	-0.20% p.a.	1.10% p.a.	-1.25% p.a.

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Results for 17 OECD Countries - 8

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM
Part 3 *continued*

	Italy	Greece	France
Diagnostics			
Equation residuals			
Standard error	2.20%	2.37%	2.23%
Normality	0.38	2.40	1.79
Kurtosis	0.86	0.27	0.10
Skewness	0.00	0.06	0.08
Heteroscedasticity	$H_{(12)} = 0.98$	$H_{(12)} = 2.63$	$H_{(11)} = 3.48$
$r_{(1)}$	0.03	-0.11	0.17
$r_{(2)}$	-0.17	-0.10	-0.08
$r_{(3)}$	0.05	-0.02	0.06
DW	1.85	2.10	1.60
Box-Ljung statistic	$Q_{(8,5)} = 5.35$	$Q_{(8,5)} = 5.57$	$Q_{(8,6)} = 3.14$
R^2	0.99	0.99	0.99
Auxiliary residuals			
Irregular			
Normality	0.15	0.75	0.17
Kurtosis	0.55	0.27	0.36
Skewness	0.04	0.54	0.12
Level			
Normality	1.69	0.17	3.89
Kurtosis	0.37	0.11	0.77
Skewness	0.99	0.02	0.09
Slope			
Normality	1.13	3.74	n/a
Kurtosis	0.02	0.07	n/a
Skewness	0.20	2.41	n/a
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	1.36	5.95	0.16
Cusum $t_{(3)}$	-0.33	-1.98**	-0.11
Likelihood Ratio Tests			
LR	75.98***	12.06***	26.08***

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Results for 17 OECD Countries - 9

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM Part 4

	Japan	Denmark	Belgium
Parameter Estimates			
y_t	0.92***	1.11***	0.74*
p_t		-0.14*	-0.18**
p_{t-1}	-0.15***		
Long-Run Elasticity Estimates			
Income (Y)	0.92	1.11	0.74
Price (P)	-0.15	-0.140	-0.18
Estimated Hyperparameters			
Irregular standard deviation	0.0040	0.0147	0.0051
Level standard deviation	0.0225	0.0330	0.0439
Slope standard deviation	0.0089	0.0071	0.0042
Trend			
Form of UEDT	Local trend	Local trend (with Irr1974 & Irr1982)	Local trend
Growth rate at end of period	-0.20% p.a.	-1.56% p.a.	0.16% p.a.

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Results for 17 OECD Countries - 10

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM Part 4*continued*

	Japan	Denmark	Belgium
Diagnostics			
Equation residuals			
Standard error	2.64%	3.93%	4.41%
Normality	3.21	0.08	4.01
Kurtosis	0.14	0.54	0.90
Skewness	1.93	0.01	0.30
Heteroscedasticity	$H_{(10)} = 0.27$	$H_{(12)} = 0.69$	$H_{(12)} = 0.56$
$r_{(1)}$	-0.04	-0.03	-0.03
$r_{(2)}$	0.12	-0.04	-0.05
$r_{(3)}$	-0.17	-0.10	0.04
DW	2.01	1.95	2.00
Box-Ljung statistic	$Q_{(8,5)} = 7.90$	$Q_{(8,5)} = 6.41$	$Q_{(8,5)} = 6.70$
R^2	0.99	0.96	0.96
Auxiliary residuals			
Irregular			
Normality	0.07	2.18	0.09
Kurtosis	0.42	0.07	0.01
Skewness	0.04	1.62	0.61
Level			
Normality	0.96	1.85	1.28
Kurtosis	0.11	1.67	0.04
Skewness	0.74	0.01	0.02
Slope			
Normality	1.75	0.06	2.69
Kurtosis	1.46	0.40	1.97
Skewness	0.09	0.03	0.04
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	0.63	0.53	0.51
Cusum $t_{(3)}$	-0.13	-0.66	-0.18
Likelihood Ratio Tests			
LR	49.07***	18.28***	26.90***

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Results for 17 OECD Countries - 11

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM Part 5

	USA	Switzerland	Spain
Parameter Estimates			
y_t	0.77***	1.01***	0.82**
p_t		-0.10*	-0.09***
p_{t-1}	-0.12**		
Long-Run Elasticity Estimates			
Income (Y)	0.77	1.01	0.99
Price (P)	-0.12	-0.10	-0.10
Estimated Hyperparameters			
Irregular standard deviation	0.0000	0.0019	0.0116
Level standard deviation	0.0178	0.0368	0.0217
Slope standard deviation	0.0049	0	0.0092
Trend			
Form of UEDT	Local trend	Local level with drift (with Irr1963)	Local trend
Growth rate at end of period	-1.42% p.a.	-0.06% p.a.	1.37% p.a.

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Results for 17 OECD Countries - 12

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM
Part 5 *continued*

	USA	Switzerland	Spain
Diagnostics			
Equation residuals			
Standard error	1.93%	3.04%	3.08%
Normality	0.09	0.85	1.48
Kurtosis	0.31	0.00	0.04
Skewness	0.07	0.36	0.70
Heteroscedasticity	$H_{(11)} = 1.54$	$H_{(12)} = 1.89$	$H_{(11)} = 0.65$
$r_{(1)}$	-0.02	-0.10	-0.01
$r_{(2)}$	-0.19	-0.01	-0.12
$r_{(3)}$	0.09	-0.07	0.25
DW	1.98	1.92	2.01
Box-Ljung statistic	$Q_{(8,5)} = 3.01$	$Q_{(8,6)} = 6.97$	$Q_{(8,5)} = 5.44$
R^2	0.98	0.98	0.99
Auxiliary residuals			
Irregular			
Normality	1.44	3.76	0.58
Kurtosis	0.01	0.78	0.03
Skewness	0.93	0.04	0.29
Level			
Normality	0.23	0.76	0.34
Kurtosis	0.10	0.54	0.22
Skewness	0.78	0.39	0.26
Slope			
Normality	1.18	n/a	0.20
Kurtosis	1.25	n/a	0.11
Skewness	0.08	n/a	0.06
Post Sample Predictive tests (1999 – 2000)			
Failure $\chi^2_{(3)}$	1.64	0.19	1.80
Cusum $t_{(3)}$	-0.40	-0.26	0.50
Likelihood Ratio Tests			
LR	81.77***	26.85***	35.70***

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Results for 17 OECD Countries - 13

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM Part 6

	Netherlands	Norway
Parameter Estimates		
y_t	1.55***	0.60**
p_t	-0.13*	-0.13*
Long-Run Elasticity Estimates		
Income (Y)	1.55	0.60
Price (P)	-0.13	-0.13
Estimated Hyperparameters		
Irregular standard deviation	0.0107	0.0164
Level standard deviation	0.0265	0
Slope standard deviation	0.0064	0.0137
Trend		
Form of UEDT	Local trend (with Irr1963)	Smooth trend
Growth rate at end of period	-2.81% p.a.	-1.04% p.a.

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Results for 17 OECD Countries - 14

Table 2: Estimated Results for Aggregate Energy Demand Using the STSM
Part 6 *continued*

	Netherlands	Norway
Diagnostics		
Equation residuals		
Standard error	4.01%	3.02%
Normality	1.05	0.91
Kurtosis	0.01	0.53
Skewness	0.01	0.47
Heteroscedasticity	$H_{(12)} = 1.33$	$H_{(12)} = 0.53$
$r_{(1)}$	-0.06	0.05
$r_{(2)}$	-0.19	-0.10
$r_{(3)}$	0.16	-0.12
DW	1.95	1.82
Box-Ljung statistic	$Q_{(8,5)} = 5.85$	$Q_{(8,6)} = 6.31$
R^2	0.99	0.99
Auxiliary residuals		
Irregular		
Normality	1.26	1.94
Kurtosis	1.01	0.04
Skewness	0.28	1.94
Level		
Normality	0.56	n/a
Kurtosis	0.01	n/a
Skewness	0.12	n/a
Slope		
Normality	0.08	1.85
Kurtosis	0.27	0.02
Skewness	0.06	1.45
Post Sample Predictive tests (1999 – 2000)		
Failure $\chi^2_{(3)}$	2.07	0.76
Cusum $t_{(3)}$	-0.30	0.07
Likelihood Ratio Tests		
LR	19.79***	58.68***

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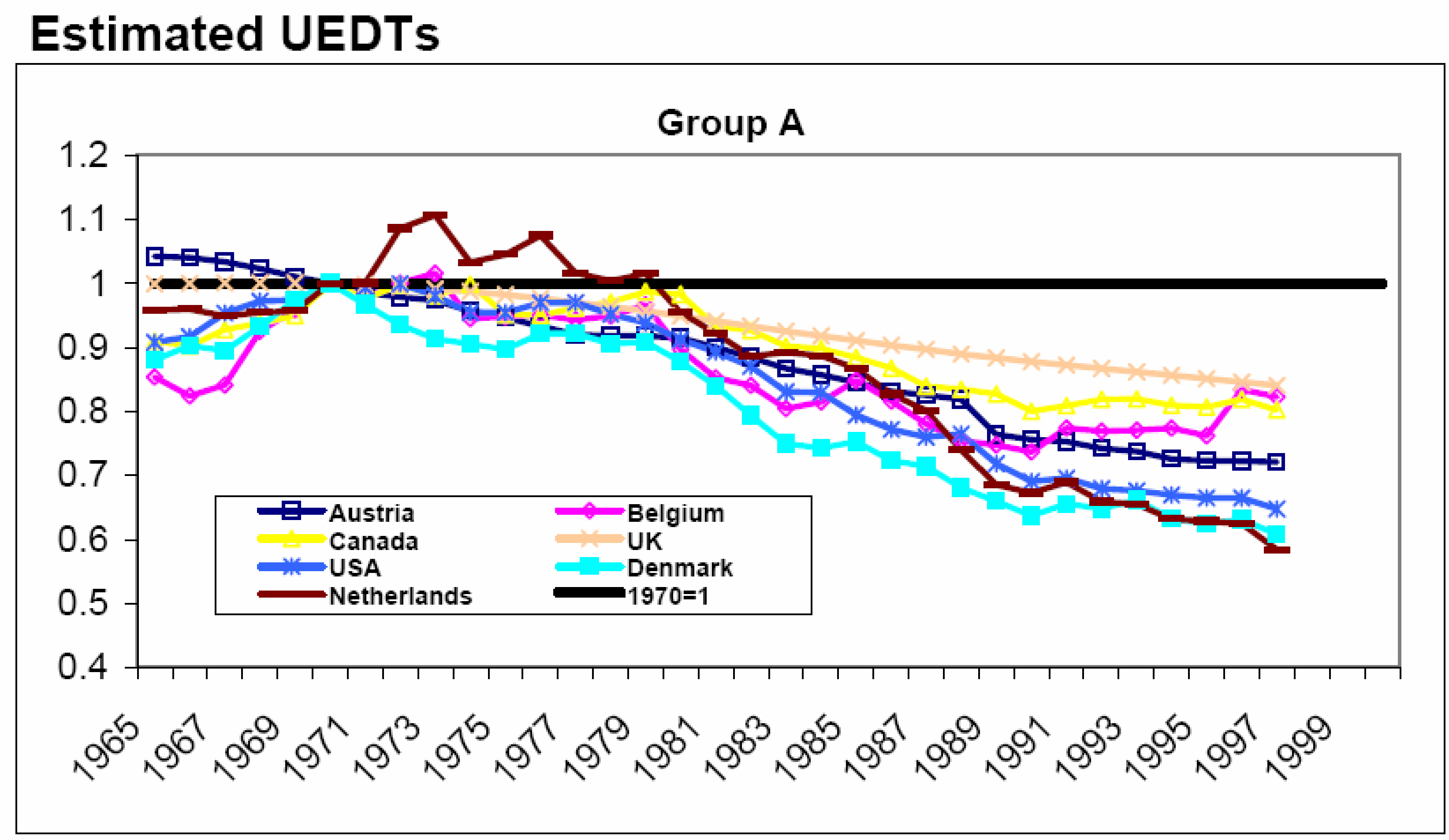
Results for 17 OECD Countries - 15

- Summary
  - In general models fit the data well statistically – other than in a couple of places
  - Give ‘sensible’ and consistent LR elasticities:
    - Most LR Income elasticity estimates are within the range 0.5 to 1.1 (But for Ireland = 0, Netherlands =1.6)
    - LR Price elasticity estimates are within the range -0.1 to -0.2
  - And, other than for Austria, the restriction of a deterministic trend over the stochastic trend is rejected.
    - It is therefore interesting to consider these trends

Estimated UEDTs - 1



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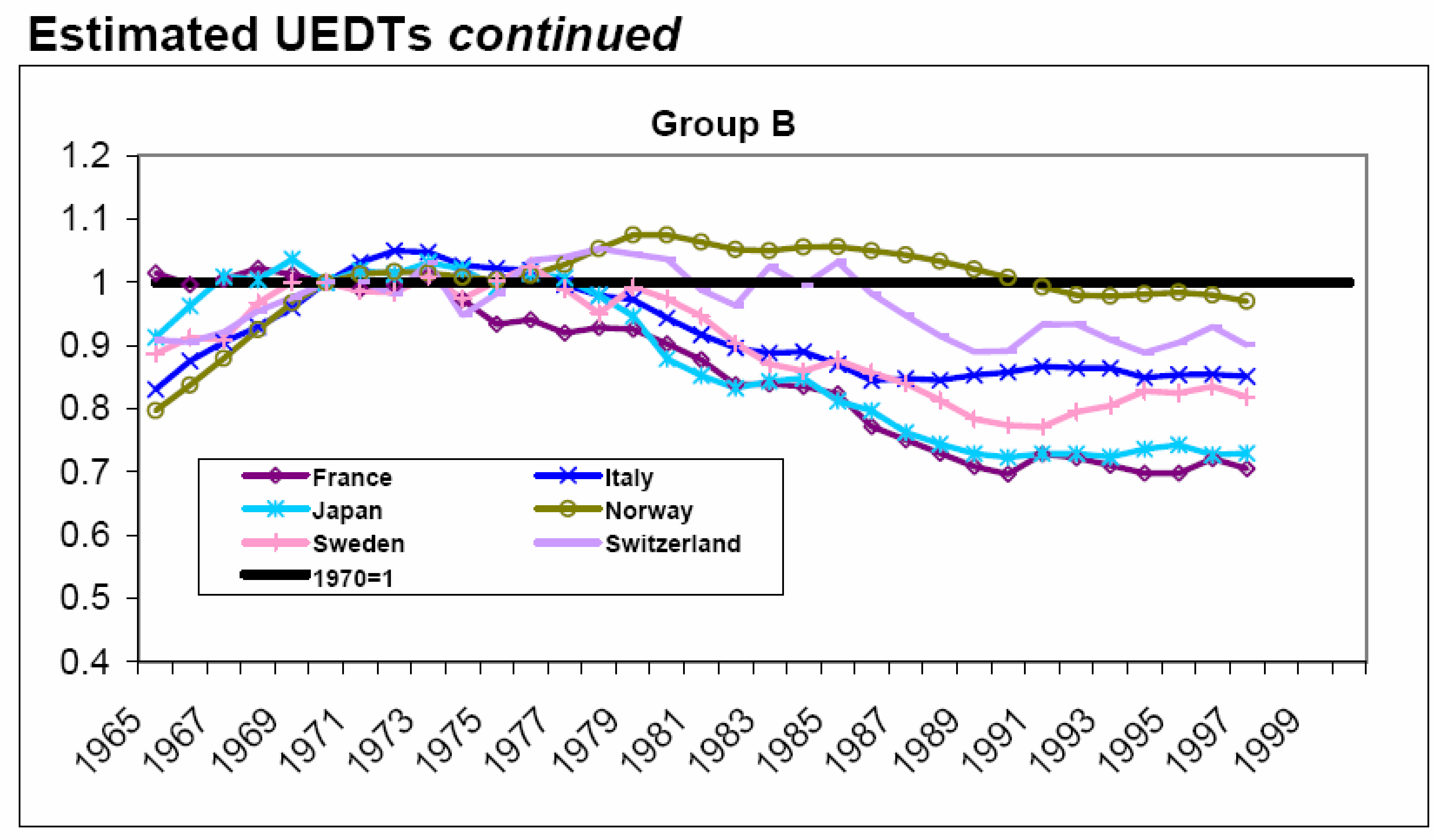
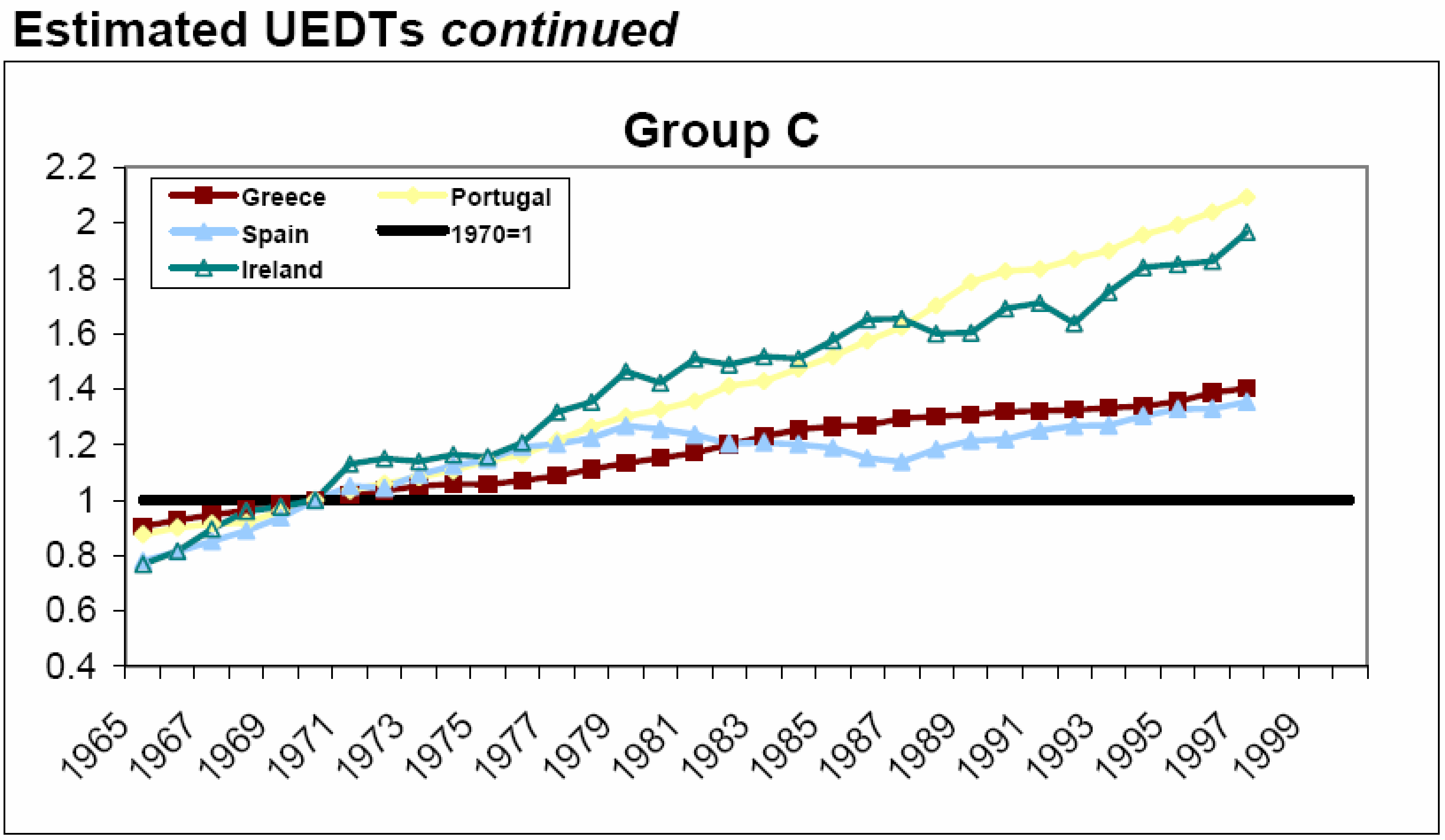
Estimated UEDTs - 2



Estimated UEDTs - 3



Estimated UEDTs - 4

- Summary
  - For Group A and Group B – generally downward sloping after the initial years.
  - But for Group C clearly upward sloping:
    - For Ireland, probably an anomaly due to zero LR income elasticity.
    - But interesting that Spain, Portugal and Greece underlying energy trend has been upward
      - Therefore, despite having similar LR income and price elasticities, these countries have been increasing their energy consumption (holding income and price constant)
      - i.e. their demand curves have been shifting outwards.

Conclusion and look to the future

- We argue here, as elsewhere, that in a time-series framework the UEDT/STSM approach is superior when estimating energy demand functions
- But still needs to be developed:
  - Need to understand and model if possible the drivers of the UEDT – since this is equally important to the understanding energy demand and predicting energy demand
  - Also link to asymmetric modelling

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