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ABSTRACT

Employing the Structural Time Series Model (STSM) approach suggested by Harvey (1989, 1997), and based on annual data for the UK from 1967-2002, this paper reiterates the importance of using a stochastic rather than a linear deterministic trend formulation when estimating energy demand models, a practice originally established by Hunt et al. (2003a,b) using quarterly UK data. The findings confirm that important non-linear and stochastic trends are present as a result of technical change and other exogenous factors driving demand, and that a failure to account for these trends will lead to biased estimates of the long-run price and income elasticities. The study also establishes that, provided these effects are allowed for, the estimated long-run elasticities are robust to the different data frequencies used in the modelling.

JEL Classification: C52, Q41

Key Words: Energy Demand, Underlying Trends.

Estimating Underlying Energy Demand Trends using UK Annual Data

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I. Introduction

Energy demand is a derived demand, not demanded for its own sake but for the services it gives in conjunction with energy using appliances and capital stock. Hence, the amount of energy demanded is dependent upon the efficiency of the appliance and capital stock. How this is captured when estimating energy demand functions has been debated for some time; in particular whether or not to incorporate a simple deterministic time trend (Beenstock and Willcocks, 1981 and 1983, Kouris, 1983a and 1983b, Welsch, 1989, and Jones 1994). More recently it has been argued that in addition to this 'technical progress' (or 'energy efficiency') effect and the normal economic and environmental variables (such as income, price and temperature) there are other important exogenous factors (such as consumer preferences and economic structure) that should also be encompassed; it therefore being unrealistic to expect a simple deterministic time trend to capture the sum of these underlying trends (Hunt *et al.*, 2003b). Furthermore, in order to capture these effects adequately, the Structural Time Series Model (STSM) suggested by Harvey (1989, 1997) is embraced allowing the Underlying Energy Demand Trend (UEDT) to be stochastic (Hunt *et al.*, 2003b).

Previous published studies using this approach have been conducted using seasonally unadjusted quarterly data. Consequently, in addition to the stochastic underlying trend, they have incorporated a stochastic approach to modelling the seasonality as opposed to the more traditional approach using deterministic quarterly dummies. Arguably, the use of both a stochastic trend and stochastic seasonals influence the estimated shape of the UEDT and the estimated income and price elasticities. Therefore, in this study an annual data set is utilised for the UK to estimate energy demand functions along with their associated UEDTs for the whole economy and the residential, manufacturing and transportation sectors. This allows for a comparison of the quarterly estimates by Hunt *et al.* (2003a) and hence an examination of whether the different frequency data has an effect on the estimated UEDTs and the estimated long-run income elasticities. The paper therefore proceeds as follows. In the following section the methodology is outlined. Section III presents the results for the various sectors of the UK followed by a summary and conclusion presented in Section IV.

II. Model and Methodology

Aggregate demand for the whole economy and the three sub-sectors are represented by:

$$e_t = \mu_t + Z_t'\delta + \varepsilon_t\,, \qquad \varepsilon_t \sim NID(0, \sigma^2_\varepsilon) \tag{1}$$

where, ***e*** is the natural logarithm of energy consumption, $\boldsymbol{\mu}$ is the stochastic trend component (the UEDT) , **Z** is a k×1 vector of explanatory variables (economic activity and real energy prices in natural logarithms plus temperature), δ is a k×1 vector of unknown parameters and ε is the disturbance term. The UEDT is assumed to follow a stochastic process:

$$\boldsymbol{\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t}, \qquad \boldsymbol{\eta_t} \sim NID(0, \sigma^2_\eta) \tag{2}$$

and

$$\boldsymbol{\beta_t = \beta_{t-1} + \xi_t}, \qquad \boldsymbol{\xi_t} \sim NID(0, \sigma^2_\xi) \tag{3}$$

where μ_t is the *level* of the trend, and the growth term β_t is known as the *slope* of the trend. The nature of the estimated UEDT depends upon zero restrictions imposed on the level, slope and the key *hyperparameters* σ^2_η and σ^2_ξ.[1] For the most restrictive case $\sigma^2_\eta = \sigma^2_\xi = 0$ the model reduces to the traditional regression model with a constant and a linear trend; a testable restricted version of the more general model given by equations (1) – (3).

For each sector, the general model in Equation (1) is formulated as an Autoregressive Distributed Lag model (ADL) starting with four lags for each variable. Estimation is carried out by calculating the maximised likelihood

[1]A full list of all possible set of restrictions is given in Hunt et al. (2003b).

function via the *prediction error decomposition* method using the *Kalman filter* incorporated in *STAMP 5.0* (Koopman *et al.*, 1995). Following the general-to-specific methodology the coefficients of insignificant variables and hyperparameters are gradually deleted according to goodness-of-fit criteria and ensuring that an exhaustive list of diagnostic tests are passed to arrive at the final preferred model.[2] In addition, the preferred models are re-estimated by imposing zero restrictions on non-zero hyperparameters in order to conduct Likelihood Ratio (LR) tests of the stochastic versus the deterministic specifications.

III. Empirical Results

Annual data for the whole economy and the residential, manufacturing and transportation sectors for the period 1967 – 2002 for aggregate energy consumption, real energy prices, economic activity and average temperature are derived from various issues of the *Digest of UK Energy Statistics (DUKES)* and its associated website and the *Office of National Statistics (ONS)* website.[3] Data for the period 1967 – 1999 are used to estimate the over-parameterised general ADL model based on equation (1) with equations (2) and (3) for each sector, saving the final three observations (2000-2002) for predictive failure tests. The results for all sectors are presented in Table 1. The estimated results for all

[2] In addition impulse dummies are included where there is some evidence of non-normality of the auxiliary residuals following Harvey and Koopman (1992) (see Hunt *et al.*, 2003b for details). However, in all cases the inclusion of the dummies has no discernable effect on the estimated elasticities or the shape of the estimated UEDTs.

[3] The activity variables, being GDP for the whole economy and the transportation sector, Real Household Income for the residential sector and the Index of Industrial Output for the manufacturing sector, are all based on 2000.

sectors are discussed in more detail below. However, it is clear that all the preferred models are free of any misspecification problems, passing all diagnostic tests including the predictive failure tests. Furthermore, other than for the residential sector, the LR tests suggest that the stochastic specifications are preferred to the deterministic versions.

{Insert Table 1 about here}

Whole Economy

No dynamic terms are needed in this model, whereas an impulse dummy for 1979 is included to ensure the normality of the auxiliary residuals but its inclusion or exclusion has no discernable effect on the estimated elasticities or the shape of the UEDT. The shape of the UEDT for the whole UK economy given in Figure 1 is the *smooth trend*, with a fixed level and stochastic slope. Although the downward shape of the estimated UEDT is characteristic throughout the sample period, there are distinct fluctuations that could not be picked up from a simple linear trend; moreover, the shape is very similar to the shape of the estimated UEDT in Hunt *et al.* (2003a), using quarterly data. The estimated long-run income and price elasticities of 0.58 and –0.13 respectively are also close to those in Hunt *et al.* (2003a) of 0.56 and –0.23 respectively – despite a different frequency and length of data.

{Insert Figure 1 about here}

Residential Sector

The average annual temperature proves to be significant for the residential sector, which is not surprising given the amount of energy required for space heating. In addition, there are some limited dynamics given the significance of lagged income. The preferred model incorporates an estimated UEDT that is the *local trend* model with a stochastic level but no slope and is very mildly upward sloping as shown in Figure 2. In this case the LR test accepts the restriction of no trend opposed to the stochastic version, however the stochastic version is retained as the preferred model since imposing the restriction leads to predictive failure over 2000-2002.[4] Although this differs slightly to the quarterly model in Hunt *et al.* (2003a), where no trend was found, it is not inconsistent given the very mild nature of the UEDT in Figure 2. Perhaps the lack of a clear downward sloping UEDT reflects the relatively poor improvements in the energy efficiency of the UK housing stock given that efficient building standards in the UK have only recently being widely established.[5] Despite the slight differences in the UEDTs the estimated long-run income and price elasticities estimated here of 0.34 and –0.23 respectively are very close to the 0.30 and –0.22 found in Hunt *et al.* (2003a).

{Insert Figure 2 about here}

[4] Given this result, further experimentation is undertaken for the residential sector by starting with the general model with a deterministic trend and testing down accordingly. This produces very similar elasticities to those in Table 1 but the problem of predictive failure persists. Therefore, the model given in Table 1, with the mild stochastic trend, is retained. All additional estimates are available from the authors on request.

[5] Notably, 86% of the housing stock in the UK was built before 1984, with almost half of that stock built before 1940. However, improvements in building regulations and insulation standards, especially since 1994, have considerably reduced energy losses (DTI, 2001, p. 26).

Manufacturing Sector

Like the whole economy the preferred model for the Manufacturing sector requires no dynamic terms and an impulse dummy for 1979. The estimated UEDT is the *local level* model presented in Figure 3. The smooth downward pattern of the estimated UEDT, especially after 1980, reflects the structural changes in the UK economy with the resultant decline in the UK manufacturing sector over the last two decades as well as the induced energy efficient effects reflected by the abnormally high price hikes of the early and late 1970s. Interestingly, when some stability was restored to oil prices the UEDT does not show any significant change in slope, reflecting the irreversibility of energy efficiency improvements.[6] Again, similar to other sectors the shape of the estimated UEDT is extremely similar to that in Hunt *et al.* (2003a) as are the estimated long run income and price elasticities of 0.70 and -0.16 respectively from this annual study compared to the quarterly estimates of 0.72 and -0.20 respectively in Hunt *et al.* (2003a).

{Insert Figure 3 about here}

Transportation Sector

This sector has the most complicated dynamics given some problems with 5th order serial correlation; hence the preferred model includes the term Δe_{t-4}.[7]

[6] Dargay (1992) amongst others have attempted to estimate possible asymmetries of the price elasticities. The estimated UEDT may in fact be picking up these effects and future research will attempt to combine the UEDT approach with asymmetric price and income elasticities.

[7] This is included since the coefficients on the fourth and fifth lags of the dependent variable are of almost equal size (in absolute terms) but of opposite signs. Therefore, the two variables (e_{t-4} and e_{t-5}) are replaced by their difference (Δe_{t-4}) that is significant.

The nature of the UEDT given in Figure 4, similar to manufacturing and the whole economy, is the *smooth trend*, but in this case it is steadily rising from the beginning of the period until about the early 1990s, but falls thereafter. Moreover the shape for the overlapping period 1972 – 1975 is similar to the quarterly model in Hunt *et al.* (2003a,); reflecting that although the increasing efficiency of the vehicle stock has a negative effect on the UEDT, this is outweighed by the effect of the increasing use of the vehicle stock (for example the greater reliance on vehicles for taking children to school, etc) resulting in the generally positive UEDT (Hunt and Ninomiya, 2003). However, for the period since the mid 1990s the estimated UEDT suggests that improved vehicle efficiency of petrol cars plus the significant increase of vehicles that run on diesel dominates[8]. Finally, despite the different length and frequency of the data sets the estimated income and price elasticities of 0.81and –0.11 respectively are once again similar to the estimates of 0.77 and –0.13 in Hunt *et al.* (2003a).

{Insert Figure 4 about here}

[8] Diesel engines are approximately 54% more efficient and also the number of diesel engine vehicles has quadrupled during the 1990s (DTI, 2000, p. 21).

IV. Summary and Conclusion

In this study, the STSM has been utilised to estimate aggregate energy demand functions for the UK whole economy and the residential, manufacturing and transportation sectors using annual data over the period 1967 to 2002. The results highlight the importance of adopting the stochastic trend formulation to estimate the UEDT when estimating energy demand functions since a simple deterministic trend is unable to capture the subtleties of the underlying exogenous effects and hence result in biased elasticity estimates. Moreover, this study shows that not only the direction and slope of the UEDT but also the estimated long-run elasticities are robust to different frequency data.

REFERENCES

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

Beenstock, M. and Willcocks, P. (1983) 'Energy and Economic Activity: A reply to Kouris', *Energy Economics*, **5**, p. 212.

Dargay, J. M. (1992) 'The Irreversible Effects of High Oil Prices: Empirical Evidence for the Demand for Motor Fuels in France, Germany and the UK', Chapter 6 in Hawdon, D. (ed.) *Energy Demand: Evidence and Expectations*, Guildford, Surrey, UK: Surrey University Press, pp. 165-182.

DTI, (2000) *Recent Developments in Transport Fuel*, Energy Trends Back Page Article, Department of Trade and Industry, UK.

DTI, (2001) *Energy Consumption in the UK*, Department of Trade and Industry, UK.

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

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

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

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

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

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

Jones, C. T. (1994), 'Accounting for Technical Progress in Aggregate Energy Demand' *Energy Economics,* **16**, 245-252.

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

Kouris, G. (1983a) 'Fuel Consumption for Road Transport in the USA' *Energy Economics,* **5**, 89-99.

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

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

Table 1 – UK Energy Demand STSM Estimates and Tests

Sample 1967-1999	Whole Economy	Residential	Manufacturing	Transportation
Estimated Coefficients				
p	-0.133 *	-0.232 **	-0.159 **	-0.113 **
	(2.65)	(5.66)	(3.13)	(3.09)
y	0.583 **		0.703 **	0.807 **
	(4.11)		(5.95)	(5.77)
y_{t-1}		0.340 **		
		(10.17)		
Δe_{t-4}				0.187 *
				(2.33)
Temp	-0.029 **	-0.070 **		
	(5.80)	(12.06)		
LR Elasticity Estimates				
Price	-0.133	-0.232	-0.159	-0.113
Income	0.583	0.340	0.703	0.807
Hyperparameters				
Irregular	0.000064	0.000170	0.000165	0.000046
Level	0	0.000021	0	0
Slope	0.000038	0	0.000103	0.000100
Nature of Trend	Smooth trend	Local level	Smooth trend	Smooth trend
Goodness-of-fit				
p.e.v.	0.000188	0.000213	0.000511	0.000237
p.e.v./m.d.^{2}	1.10	1.12	0.93	1.08
R^2	0.90	0.97	0.99	0.99
R_d^2	0.78	0.89	0.76	0.67
Diagnostics				
Residuals				
Std.Error	0.014	0.015	0.023	0.015
Normality	0.75	1.90	1.86	0.71
Skewness	0.21	1.78	0.01	0.34
Kurtosis	0.54	0.11	1.85	0.37
H(10)	0.61	0.77	1.64	1.87
r(1)	0.07	0.05	0.08	0.01
r(7)	0.07	-0.19	0.06	0.09
DW	1.80	1.88	1.76	1.89
Q(7,6)	6.85	6.25	5.56	4.88
Auxiliary Residuals				
Irregular				
Normality	1.12	0.29	0.79	1.14
Skewness	1.06	0.28	0.43	0.90
Kurtosis	0.06	0.01	0.36	0.24

Sample 1967-1999	Whole Economy	Residential	Manufacturing	Transportation
Level				
Normality	N/A	0.36	N/A	N/A
Skewness	N/A	0.32	N/A	N/A
Kurtosis	N/A	0.03	N/A	N/A
Slope				
Normality	0.26	N/A	0.58	0.91
Skewness	0.04	N/A	0.57	0.05
Kurtosis	0.22	N/A	0.01	0.87
Predictive tests 2000-2002				
Failure	1.73	7.32	4.33	3.48
Cusum t(30)	-1.31	-2.50	1.07	-1.06
LR tests	24.3**	0.33	49.7 **	44.5**

Notes:

- *Model estimation and t-statistics (in parenthesis) are from STAMP 5.0;*
- **, ** Denotes significance at 5% and 1% level respectively;*
- *Models for the Whole Economy and the Manufacturing sector include a dummy for the year 1979;*
- *Prediction Error Variance (p.e.v.), Prediction Error Mean Deviation (p.e.v./m.d.^{2}) and the Coefficients of Determination (R^2 and R_d^2) are all measures of goodness-of-fit;*
- *Normality (corrected Bowman - Shenton), Kurtosis and Skewness are error normality statistics, all approximately distributed as $\chi^2_{(2)}$; as $\chi^2_{(1)}$; as $\chi^2_{(1)}$ respectively;*
- *H(10) is a Heteroscedasticity statistic distributed as $F_{(10,10)}$;*
- *r(1) and r(7) are the serial correlation coefficients at the equivalent residual lags, approximately normally distributed;*
- *DW is the Durbin-Watson statistic;*
- *Q(7,6) is the Box – Ljung statistic distributed as $\chi^2_{(6)}$;*
- *Failure is a predictive failure statistic distributed as $\chi^2_{(3)}$;*
- *Cusum is a mean stability statistic distributed as the Student t distribution;*
- *LR represent likelihood ratio tests on the same specification after imposing a zero level or slope hyperparameter distributed as $\chi^2_{(1)}$.*

Figure 1 – Whole Economy Trend – Log Scale

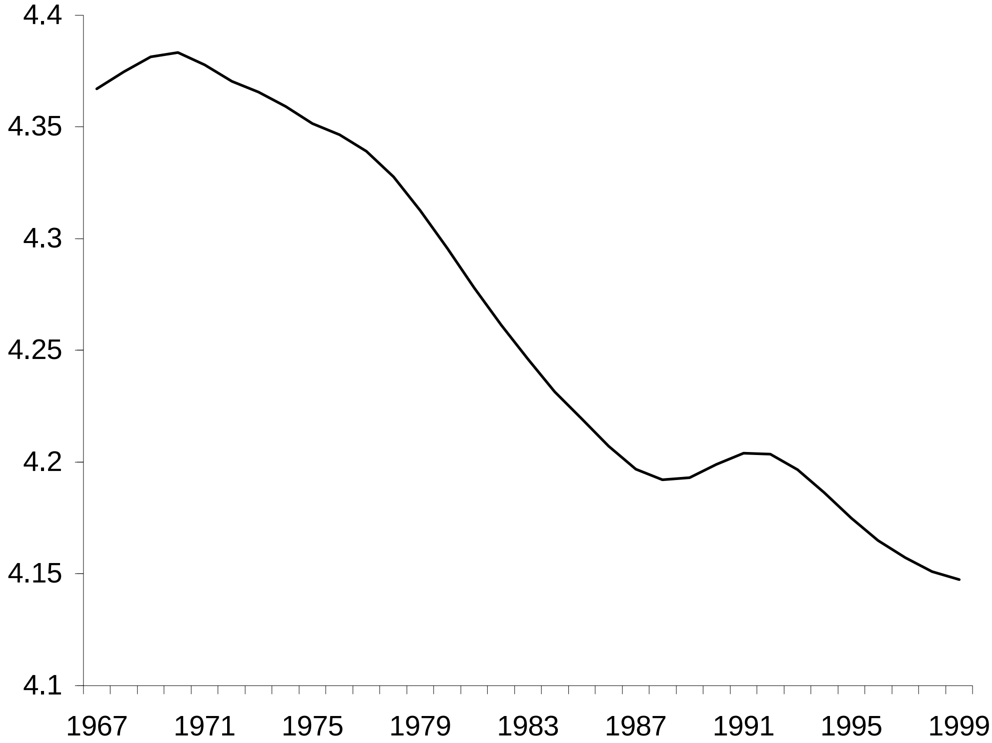


Figure 2 – Residential Sector Trend – Log Scale

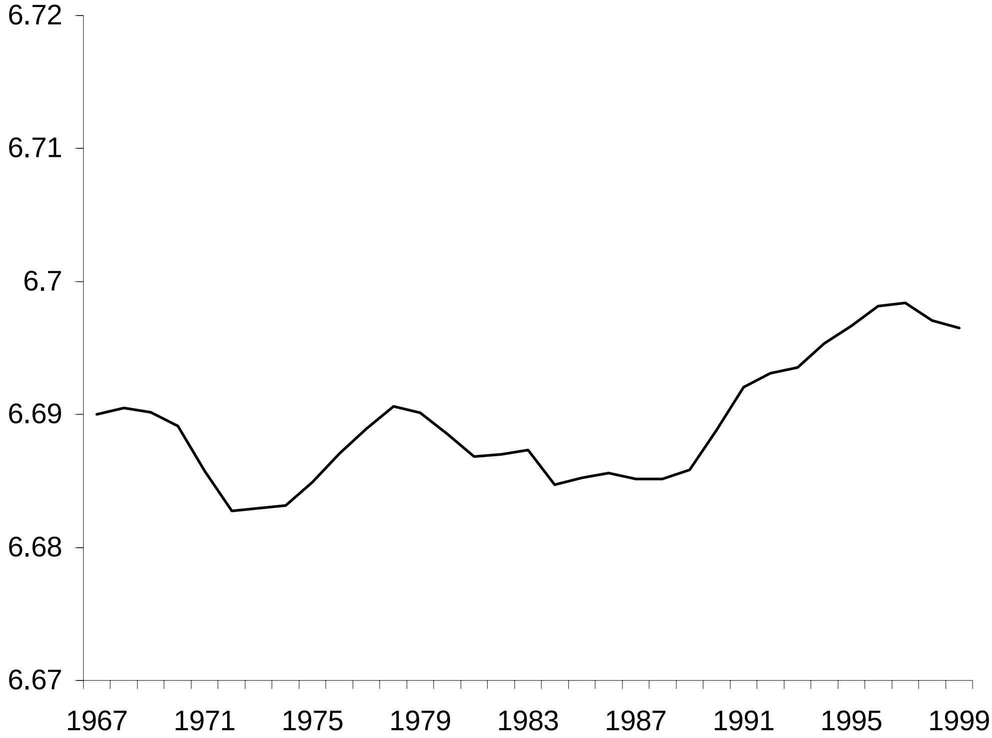


Figure 3 – Manufacturing Sector Trend – Log Scale

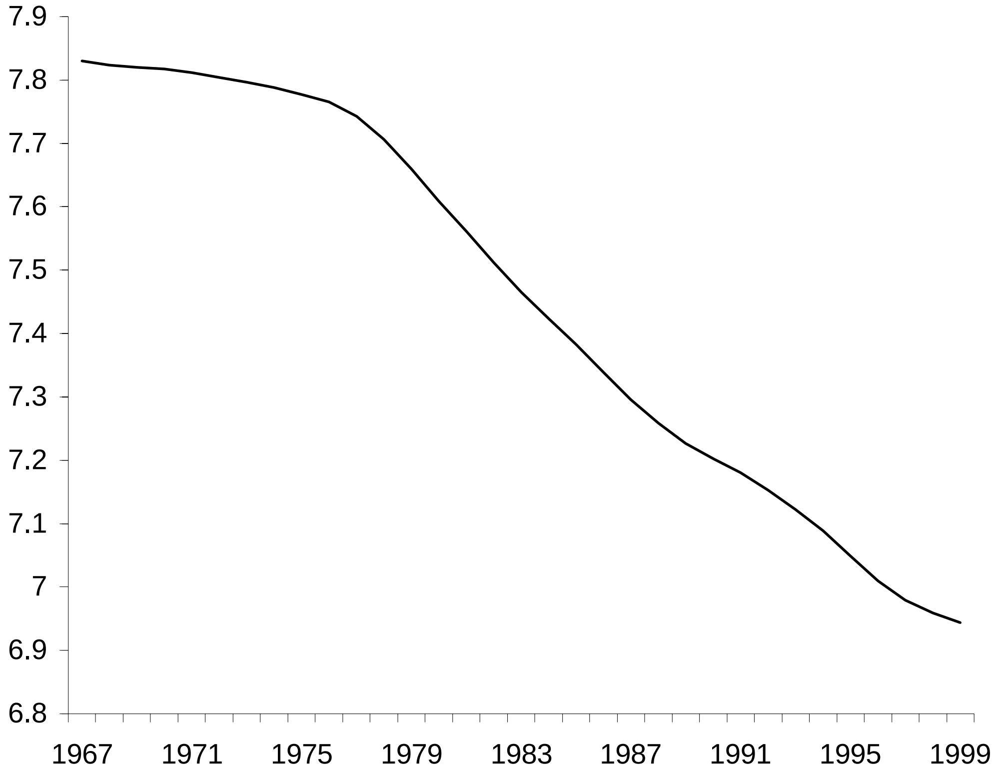
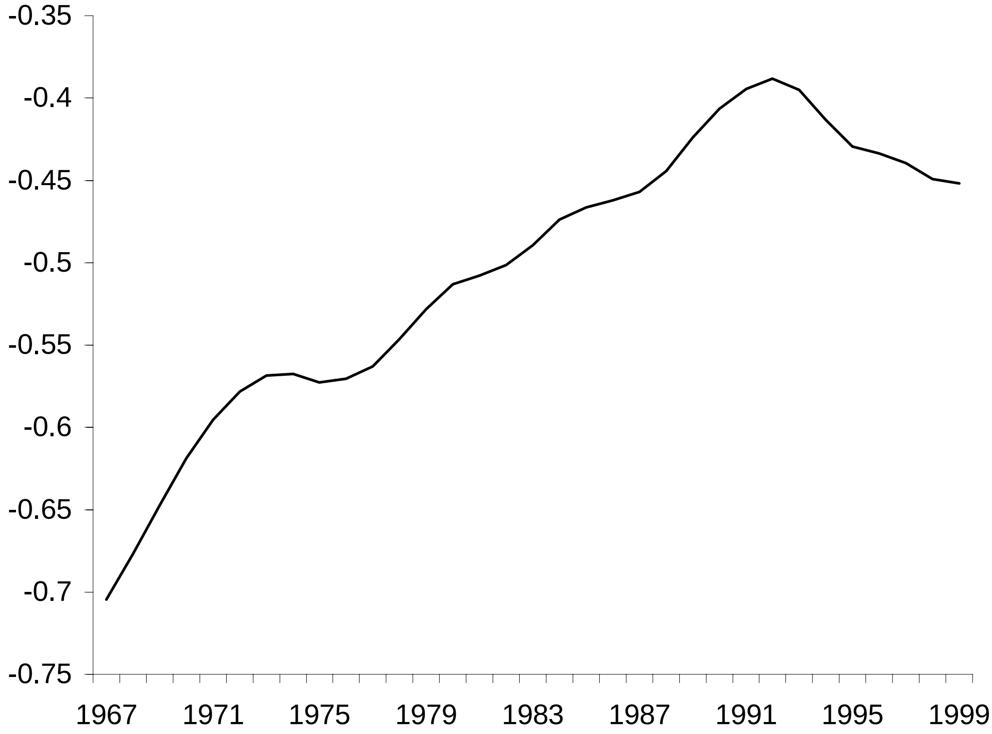


Figure 4 –Transportation Sector Trend – Log Scale



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