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# An Empirical Analysis of the Long-run Energy Demand in Japan: 1887 – 1998

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**ABSTRACT**

This paper examines the long-run relationship between energy demand, GNP and energy price in Japan using data covering 1887 – 1998. It is found that, if an underlying energy demand trend (UEDT) is appropriately incorporated, an econometric model produces a long-run income elasticity of unitary and a long-run price elasticity of –0.15. This means that over the past hundred years there was a stable one-to-one linkage between energy demand and GNP. In contrast, the impact of the price changes was much smaller. The estimated model is utilised to forecast energy consumption and $CO_2$ emissions up to 2015. The results suggest that Japan needs a considerable effort to reduce the growth in energy consumption and hence $CO_2$ emissions in order to meet the 1997 Kyoto Protocol agreed emission level; through governmental policies such as environmental regulation, R&D incentives, and education for energy conservation as well as pricing policy. In fact, it is shown that, even if GNP only grows by approximately 1¼% p.a., price of energy would need to increase by more than 5% p.a. in order to achieve the Kyoto target.

***Keywords: Japan, energy demand, GNP, elasticity, underlying trend,*** ***$CO_2$ emission.***

***JEL Classifications : C52, Q41.***

# I INTRODUCTION

For the past one hundred years, Japan has experienced dramatic changes in economic and social structure. People's life styles as well as in its political system have changed beyond all recognition. Between 1900 and 1998 real per capita GNP in Japan increased by some 15 times, from 253,000 to 3,917,000 1990 Yen. This rapid economic growth is sometimes referred to as a 'miracle' in comparison to other OECD countries (Burda and Wyplosz, 1993, p.152). For example, over the same period, per capita GNP increased by only 4 to 5 times in the UK and US, and by around 7 times in Germany and France (Maddison, 1989) (*EDMC*, 1999). It indicates that Japan passed through many stages, from an economically developing country to an advanced country within a relatively short period.

Energy consumption in Japan has also risen drastically over the past hundred years. Between 1900 and 1998, primary energy consumption per capita expanded by about 18 times, from 2,395,000 Kcal to 44,273,000 Kcal. This growth was also much faster than other OECD countries. Primary energy consumption in the UK, for instance, increased by just 2.3

times over the same period (Fouquet and Pearson, 1998).

A substantial number of econometric studies on energy demand have been conducted. See Atkinson and Manning (1995) for a survey of developed countries and Dahl (1994) for a survey of developing countries. However, very few of them use long-term data covering for more than 50 years. For example, Stern (2000) uses US annual energy data for 1948 – 1994, and Bentzen and Engsted (1993) uses Danish annual data for 1948 – 1990: both use considerably longer data than other studies but still less than 50 years. The likely reason for not using long term data for energy demand studies is the lack of reliable and consistent energy data taken over long periods.

Fortunately such a long data set is available for Japan. It is therefore of interest to investigate the relationships between energy demand, output, and the real energy price over a longer term because such historical data may contain useful information which sheds light on the evolution of energy demand when an economy grows from the developing stage to the advanced stage. In addition, since the mode of energy usage also changed dramatically as well as shifting in main energy resources from wood and coal to petroleum over the past century as seen in Table 1, it is also interesting to see if these changes affect the relationship between energy, GNP and the real energy price.

**Table 1: Proportion of each resource in primary energy consumption in Japan**

| Year | Coal | Petroleum | Natural Gas | Hydro | Nuclear | Wood & briquette | Others |
|---|---|---|---|---|---|---|---|
| 1900 | 44.8 | 3.5 | - | - | - | 51.6 | - |
| 1925 | 74.7 | 3.2 | 0.1 | 10.8 | - | 11.2 | - |
| 1950 | 51.5 | 6.3 | 0.1 | 33.0 | - | 9.0 | - |
| 1975 | 16.4 | 73.4 | 2.5 | 5.3 | 1.5 | 0.1 | 0.9 |
| 1997 | 16.9 | 53.6 | 11.6 | 3.8 | 12.9 | 0 | 1.3 |

*Source: EDMC (1999)* (%)

This paper therefore examines the long-run relationship between energy demand, GNP and energy price in Japan using data covering 1887 – 1998. In addition, the estimated relationship is utilised to create various scenarios for energy consumption and hence $CO_2$ emissions up to 2015. This paper is organised as follows. The next section and Section III describe the data and the model employed in this study. Section IV reports the estimated results followed by Section V which presents the forecasts of results, based on the preferred model in the previous section. The final section concludes the paper.

## II DATA

The annual data for primary energy consumption per capita (1,000 Kcal/Person) in Japan between 1887 and 1998 were taken from *EDMC* (1999) and the Ministry of International Trade and Industry (MITI) Web site.[1] Figure 1 shows plots of this series in logarithms. The huge drop during the early 1940s was caused by World War II and the subsequent economic disruption. In addition, a stagnation during the late 1970s and the early 1980s occurred after the oil crisis. Except for these two periods, the energy consumption increased almost constantly over one hundred years. The consumption grew at a relatively consistent rate (4.1% p.a. on average) until 1940, although some cyclical volatility is also observed. A very strong expansion at a steady rate (8.4% p.a. on average) over the quarter of the century between 1947 and 1974 is clearly distinguishable from the rest of the period. Although between 1975 and 1986, energy consumption was relatively stable, after 1986, it resumed increasing at the moderate growth

[1] *http://www.miti.go.jp* (in Japanese) downloaded on 16th August 2000.

rate of 2.2% p.a. on average.

The annual data for real GNP per capita (1990 price) between 1887 and 1998 was also taken from *EDMC* (1999)[2] and the Economic Planning Agency, Japan (EPA).[3] The plot of this series in logarithms shown in Figure 2 broadly resembles that of the energy consumption. Between 1887 and 1941, the real GNP increased at an average rate of 2.0% p.a.. This period is characterised by continuous cyclical fluctuations. This volatility was generated by fierce competition throughout the economy causing frequent bankruptcies in every industry (Hamori and Hamori, 2000) as well as political instabilities. World War II (1939 – 1945) completely destroyed the Japanese economy resulting in the massive drop in GNP back to its level in the early 1890s. However, after 1946, the economy began to grow very strongly. Between 1946 and 1973, GNP continued to increase by 7.4% p.a. on average. After 1974, it still increased steadily but its growth rate declined to 2.6% p.a. on average.

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[2] Since per capita real GNP in 1945 is not reported in *EDMC* (1999), this value was estimated by the author.

[3] *http://www.epa.go.jp/2000/g/qe001-2/nen.gif* (in Japanese) downloaded on 16th August 2000.

**Figure 1: Primary energy consumption per capita in Japan, 1887 – 1998 (log scale)**

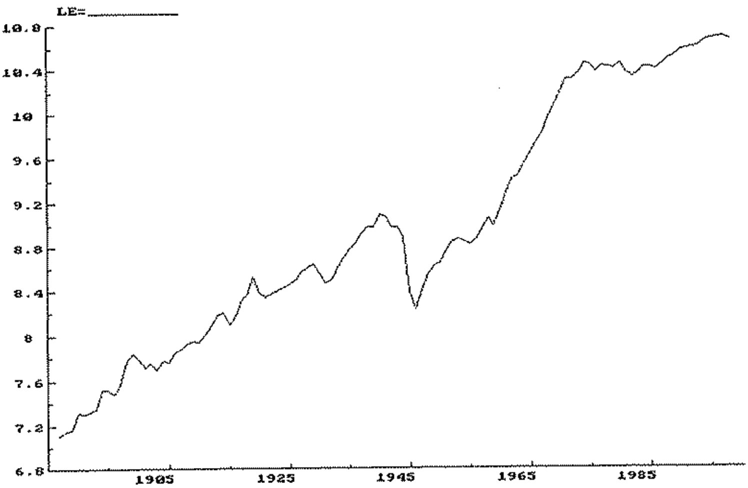



**Figure 2: Real GNP per capita (1990 price) in Japan, 1887 – 1998 (log scale)**

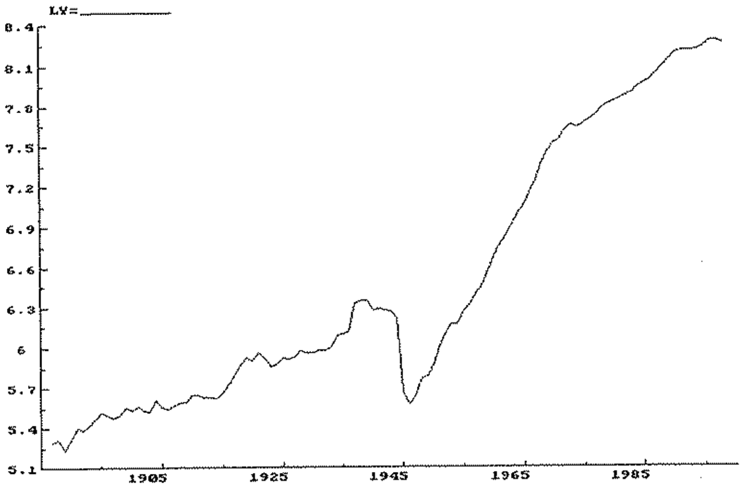
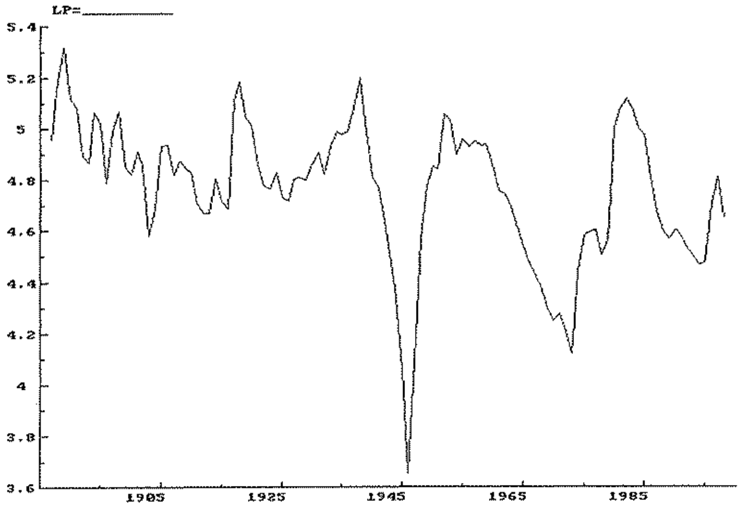


**Figure 3: Real energy price (1990 price) in Japan, 1887 – 1998 (log scale)**




A continuous series of real energy prices in Japan over the period 1887 – 1998 has not been officially published. Therefore, the data series was constructed using the following various energy price indices: the wholesale price index of Coal for 1887 – 1930, the wholesale price index of Fuels for 1931 – 1951, and the wholesale price index of Fuels and Energy for 1952 – 1998. All were taken from various issues of Wholesale Price Index (The Bank of Japan). The constructed continuous series was deflated by 1990 price GNP deflator (*EDMC*, 1999) to give the real energy price index from

1887 to 1998 as shown in Figure 3. Similar to the previous two series, there were small cyclical fluctuations within a moderate range for the period up to the early 1940s. An enormous reduction in the mid-1940s was a result of relative unbalance against general price level caused by hyperinflation which recorded a 1,075% rise between 1944 and 1946. The 1950s, 1960s and the early 1970s were characterised by a steady decline in the real energy price which was suddenly interrupted by a massive jump in 1974. Following a small decline in 1978, the real energy price continued to rise reaching a peak in 1982, one of the highest levels over the sample period.

## III MODEL

It is assumed that aggregated energy demand is defined by the following function:

$$E = f(Y, P, \mu) \qquad (1)$$

where:

$E$ = aggregated energy demand

$Y$ = GNP

$P$ = aggregated energy price

$\mu$ = underlying trend (technical progress, change in tastes etc.)

Furthermore, following Hunt *et al.* (2000b), the function is specified as a combination of a log linear autoregressive distributed lag (ARDL) model and Harvey's structural time series model within a space state form framework (Charemza and Deadman, 1997) (Harvey, 1989). The functional form of Equation (1) is assumed to be:

$$A(L)\ln E_t = \mu_t + B(L)\ln Y_t + C(L)\ln P_t + \varepsilon_t \qquad (2)$$

where:

$$A(L) = \phi_0 - \sum_{i=1}^{p}\phi_i L^i \, , \phi_0 = 1$$

$B(L) = \sum_{i=0}^{q} \gamma_i L^i$

$C(L) = \sum_{i=0}^{s} \delta_i L^i$

$L^i$ = the lag operator for $i^{th}$ order

$\varepsilon_t$ = residuals.

Beginning with a fairly generous lag length, the model was successively tested down until the most parsimonious model was obtained. This was guided by a battery of diagnostic tests. The solved static long-run equation is given by:

$$\ln E_t = \mu_t + \Gamma^* \ln Y_t + \Pi^* \ln P_t + \varepsilon_t \quad (3)$$

where the long-run income elasticity[4] of the energy demand $\Gamma^*$ is given by:

$$\Gamma^* = \frac{\sum_{i=0}^{q} \hat{\gamma}_i}{1 - \sum_{i=1}^{p} \hat{\phi}_i} \quad (4)$$

similarly, the long-run price elasticity of the energy demand $\Pi^*$ is given by:

[4] Strictly speaking, this should be called GNP elasticity. However, we use the common notation of income elasticity as GNP is an approximation of income.

$$\Pi^* = \frac{\sum_{i=0}^{s} \hat{\delta}_i}{1 - \sum_{i=1}^{p} \hat{\phi}_i} \tag{5}$$

Moreover, as a transition equation, the underlying trend $\mu_t$ is assumed to have the following stochastic process:

$$\begin{bmatrix} \mu_t \\ \beta_t \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \mu_{t-1} \\ \beta_{t-1} \end{bmatrix} + \begin{bmatrix} \eta_t \\ \xi_t \end{bmatrix} \tag{6}$$

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

$\mu_t$ and $\beta_t$ represent the stochastic level and the stochastic slope components respectively. The optimal estimates of $\mu_t$ and $\beta_t$ minimising the prediction error variance in each period are calculated by the Kalman filter and the smoothing algorithm. Therefore, we can see the pattern of the estimated trend over the sample. If and only if $\sigma_\eta^2 = 0$ and $\sigma_\xi^2 = 0$, the underlying trend becomes a familiar linear deterministic time trend, namely, $\mu_t = \alpha + \beta t$. In this case, the trend increases or decreases at the fixed rate $\beta$ over the sample period. Obviously, it is the restricted special case in this framework.

The importance and role of the stochastic trend for energy demand analysis are extensively discussed in Hunt *et al.* (2000a and 2000b). They stress that the underlying trend in energy demand should be thought of as more than just 'technical progress' and therefore introduce the idea of the 'Underlying Energy Demand Trend (UEDT)'. This encompasses the technical progress effect but also those due to changes in economic structure and consumer tastes. Given the different influence of the UEDT, it is unlikely to be modelled adequately by a restricted linear deterministic time trend. Therefore, the greater flexibility of the trend in the structural time series model would significantly contribute to obtaining unbiased estimators for the long-run elasticity of energy demand.

Equations (2) and (6) constitute a space state form which was estimated by the Kalman filter[5] using the Japanese data for 1887 to 1998, holding data from the 1990s (9 observations) for the predictive failure tests. The number of lags for each variable was tested down to one ($p = q = s = 1$) since any higher lagged variables were always very insignificant. Hence, the model

[5] The soft ware package STAMP 5.0 (Koopman *et al.*, 1995) was used for the Kalman filter estimation.

was restricted to be ARDL (1,1,1). Along with the general model with a stochastic trend, two alternative models with deterministic trend specifications were also estimated to see how they affect the estimated results and diagnostics of the models[6]. The trend specifications of the estimated three models are summarised as follows.

Model 1: A stochastic trend i.e. at least either $\sigma_{\eta}^{2} \neq 0$ or $\sigma_{\xi}^{2} \neq 0$

Model 2: A deterministic linear time trend i.e. $\mu_t = \alpha + \beta t$

Model 3: No trend i.e. $\mu_t = \alpha$.

Models 2 and 3 are familiar conventional models with a time trend or without a time trend which can be estimated by OLS. However, Model 1 cannot be estimated by OLS and the Kalman filter is used instead.

[6] For both Model 2 and Model 3, a general ARDL model was estimated and tested down in a similar fashion to Model 1. In all cases, the preferred models were ARDL (1,1,1).

## IV RESULT

Table 2 reports a summary of the estimated results and diagnostics of each model.[7]

**Table 2: Estimated results for three models of primary energy demand in Japan 1887 – 1989**

| | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| ***Estimated long-run elasticities*** | | | |
| Income | 1.055 | 0.776 | 0.995 |
| Price | -0.150 | -0.289 | -0.473 |
| ***Type of underlying trend*** | Stochastic | Deterministic | No trend |
| ***Growth rate of trend at the end of the sample period*** | -0.48% p.a. | 0.13% p.a. | None |
| ***Diagnostics*** | | | |
| Standard Error | 0.05 | 0.05 | 0.05 |
| Normality | 1.68 | 0.61 | 1.38 |
| H (33) | 0.32 | 0.46 | 0.50 |
| r (1) | 0.04 | 0.05 | 0.03 |
| r (9) | -0.01 | 0.04 | 0.02 |
| RESET | 1.00 | 10.44** | 13.10** |
| DW | 1.87 | 1.85 | 1.91 |
| Box-Ljung Q | $Q_{(9,8)}$= 7.43 | $Q_{(9,9)}$= 6.57 | $Q_{(9,9)}$= 6.12 |
| Prediction error variance × $10^3$ | 2.65 | 2.73 | 2.80 |
| $R^2$ | 0.99 | 0.99 | 0.99 |
| $R_d^2$ | 0.67 | 0.65 | 0.65 |
| ***Predictive failure test (1990 – 1998)*** | | | |
| Failure $\chi^2_{(9)}$ | 2.35 | 4.04 | 3.12 |
| Cusum *t* (100) | 0.33 | -1.57 | -1.21 |

**Notes: 1.** Normality is the Bowman-Shenton statistic, approximately distributed as $\chi^2_{(2)}$;
H(33) is the test for heteroscedasticity, approximately distributed as $F_{(33,33)}$;
r(1) and r(9) are the serial correlation coefficients at the 1st and 9th lags respectively, approximately distributed as N(0,1/*T*);
RESET is Ramsey's regression specification error test statistic which is distributed as $F_{(1,90)}$;
DW is the Durbin Watson Statistic;
$Q_{(9,n)}$ is the Box-Ljung Q-statistics based on the first 9 residuals autocorrelation and

[7] PcGive 9.0 (Hendry and Doornik, 1996) was also used for the estimation of the conventional models.

distributed as $\chi^2_{(n)}$;

$R^2$ is the coefficient of determination;

$R_d^2$ is the coefficient of determination based on the first difference (Harvey, 1989, p.268);

$\chi^2_{(9)}$ is the post-sample predictive failure test;

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

2. ** Indicates significant at the 1% level.
3. Impulse dummy variables for 1891, 1898, 1940 and 1959 are included in all models.
4. The estimated long-run elasticities are based on the short-run parameters which are significantly different from zero at least 5% error level.

Model 1, with the stochastic trend, passes all the diagnostics comfortably and there is no sign of mis-specification. The estimated long-run income elasticity is unitary indicating the existence of a one-to-one long-run relationship between energy demand and GNP over the sample period. In contrast, the estimated price elasticity is –0.15 suggesting that the impact of price change on the demand is much smaller. The underlying trend in the preferred model is characterised by a fixed level and stochastic slope component i.e. $\sigma_\eta^2 = 0$ and $\sigma_\varsigma^2 \neq 0$. In this case, the trend slowly and smoothly changes its direction over the sample period. Its growth rate at the end of the estimation period (1989) is –0.48% p.a., suggesting, even after compensating income and price effects, the energy demand would autonomously fall by 0.48% each year.[8]

[8] The estimated trend will be discussed further in the later section.

Model 2 with, a familiar linear deterministic time trend, has a substantially large RESET statistic, indicating possible mis-specification. The likelihood ratio (LR) test for the restriction of the deterministic trend on the stochastic trend clearly rejects the null hypothesis that the restriction is valid at even at the 1% level.[9] In addition, the prediction power of the model is considerably worse than Model 1.[10] Therefore, compared to Model 1, the estimated long-run income elasticity of 0.77 and price elasticity of –0.29 are likely to be under-estimated and over-estimated (in absolute terms) respectively. The estimated trend in growth is a positive value of 0.13% p.a. implying the demand would increase even after removing income and price effects.

Similar to Model 2, the RESET test indicates that Model 3 is also mis-specified and the estimated results from this model are unreliable.[11] Therefore, the substantially larger (in absolute terms) long-run price elasticity of –0.47 estimated by this model is likely to be an over-estimated

[9] The LR is 12.35.
[10] [11] Moreover, no co-integrating vector was found in Model 2 and Model 3 suggesting the stochastic components in the variables may distort the statistical properties of the models.

result. The model assumes non-existence of the trend implying the energy demand is solely driven by changes in income and price, and that there is no impact of technical progress in energy use, changes in economic structure on the demand, or these effects are exactly cancelled out each other. In other words, if income and price remain constant, energy demand would also remain constant. The mis-specification sign of the model suggests that this is a wrong assumption.

From the above argument, it is reasonable to conclude that Model 1 is preferred to Model 2 and Model 3. It is useful to compare the estimated elasticities from Model 1 with the results given by the past studies of aggregated energy demand in Japan. In terms of the long-run income elasticity, there is a consensus range between 0.8 and 1.2 for the most of the past studies.[12] The unitary income elasticity estimated in this study falls in the middle of this range. In contrast, for the long-run price elasticity, there are a variety of estimates ranging from –0.13 (Smith *et al.*, 1995) to –0.88 (Brenton, 1997). The estimated price elasticity in this paper of –0.15 is

[12] For example, Brenton (1997), Koshal *et al.* (1989), Welsh (1989), and Fiebig *et al.* (1987) estimate 1.34, 0.76,1.23, and 1.27 respectively.

among the smallest (in absolute terms) but close to that obtained by Smith *et al.* (*op cit.*). These differences appear to be a result of the approach taken to modelling the underlying trend. In this study and Smith *et al.* (*ibid.*), the underlying trend is estimated stochastically, whereas the other studies employ a linear time trend or it is ignored completely. Note that similar over-estimations of the long-run price elasticities were estimated by Model 2 and Model 3 in the above. See Hunt *et al.* (2000b) for the discussion about this issue.

It is also worth further considering the trend in Model 1 in more detail. The estimated underlying trend for the preferred model 1 is shown in Figure 4. The trend exhibits a non-linear inverse U-shape implying that there were two distinct stages of energy use in the Japanese economy: energy using period (1887 – 1945) and energy saving periods (1945 – 1989). The positive curve up to 1945 suggests that the economy became more energy-intensive holding output and price levels constant. In contrast, after 1945, the underlying trend is downward indicating that the economy became an energy-saving holding output and price constant.

**Figure 4: Estimated underlying energy demand trend in Japan 1887 – 1989**

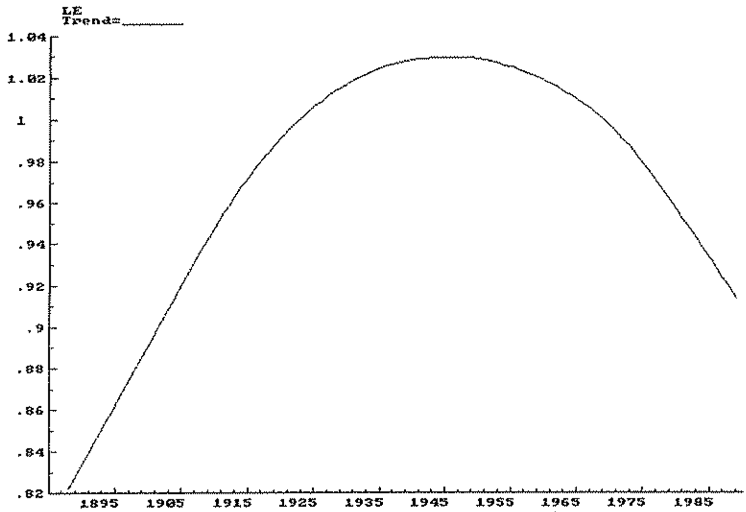



**Figure 5: Estimated slope of the underlying trend in Japan 1887 - 1989**

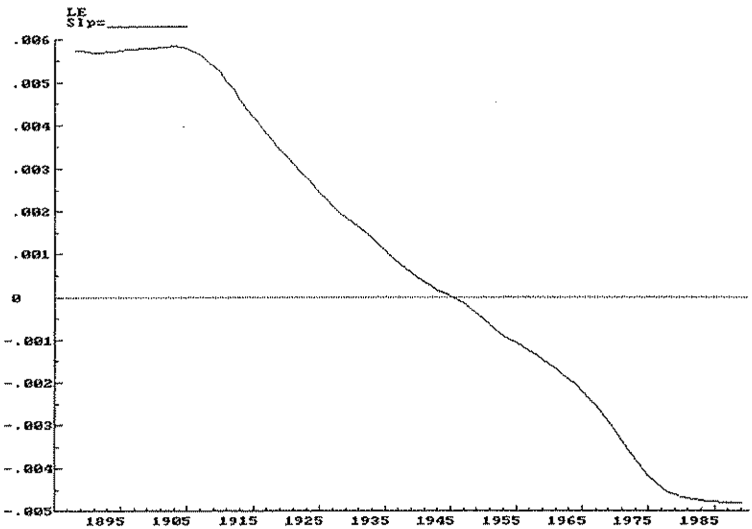


Figure 5 shows the slope of the underlying trend.[13] This illustrates that the slope was relatively stable from 1887 to the mid 1900s. hence, the trend increased at the almost fixed rate of 0.58% p.a.. After then, the slope continuously declined until the mid-1980s. Even when the economy became energy intensive (between 1910 and 1945), the growth in intensity was being continuously smaller which eventually led to the negative trend after 1945. The slope of the trend seems to approach the fixed rate of around –0.45% p.a. at the end of the sample period. Again, this suggests that the energy demand would decrease by approximately 0.5% p.a. when GNP and energy price remain unchanged.

[13] This is the equivalent of the first derivative of the trend.

## V FORECAST

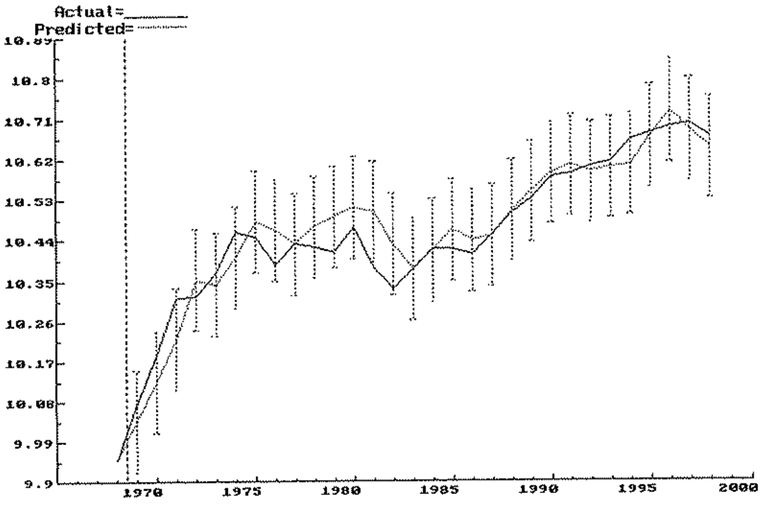
Given Model 1 is the preferred model, the stability of the estimated parameters in the model were further tested over the much longer period, 30 years, in order to confirm its forecasting ability. The model was re-estimated using the data from 1887 to 1968,[14] with the post-sample prediction tests for the period between 1969 and 1998. Figure 6 shows the post-sample predicted and actual primary energy consumption over the post-sample period, from 1969 to 1998. The model predicts the actual energy consumption over 30 years between 1969 and 1998 very well. All actual values are within the prediction intervals except 1981 for which it just lies on the boundary. The post-sample predictive failure test statistics ($\chi^2_{(30)}$) is 22.18 and the Cusum *t*-statistics for the parameter consistency test (*t* (79)) is –0.94. This suggests that the parameters are stable over 30 years and, hence, the forecasting ability of the model is likely to be reliable.

Furthermore, a set of dummy variables was used to test for shifting the intercepts and changes in the slopes of the coefficients for a various sub-

[14] The estimated long-run income elasticity is 0.926 which is still close to the estimate using the data 1887 – 1989.

sample periods. For example, the data were divided into two periods, 1887 – 1945 (pre-war period) and 1946 – 1998 (post-war period), and 1887 – 1952 (pre-high growth period) and 1953 – 1998 (high growth period) and others. Since none of the dummy variables were significant at even the 10% level, it can be concluded that the parameters in model 1 are stable over the different sub-sample periods.

**Figure 6: Predicted and actual primary energy consumption per capita in Japan 1969 – 1998 (log scale)**




**Note :** The prediction intervals are set at twice of the root mean square errors.

Given the stable relationship, the model was re-estimated over the full sample period (1887 – 1998) in order to generate the forecasts of energy demand in Japan for the period 1999 to 2015. The estimated long-run income and price elasticities were 1.04 and –0.15 respectively, which are very similar to the estimates of Model 1 in Table 2.

Since GNP was found as a main driving factor of the energy demand, three cases were assumed as follows: 1) a low GNP growth case, 2) a medium GNP growth case, 3) a high GNP growth case. The GNP growth rates in each scenario are summarised in Table 3.

**Table 3: Real GNP per capita growth rate assumptions in each case**

| | 2000 | 2000 – 2005 | 2006 – 2015 |
|---|---|---|---|
| Low growth case | 1.0 | 1.8 | 0.9 |
| Medium growth case | 1.7 | 2.5 | 1.9 |
| High growth case | 2.5 | 3.0 | 2.5 |

(%)

The growth rates for 2000 (1.0%, 1.7%, and 2.5%) were based on the predictions given by the Economic Planning Agency of Japan,[15] OECD,[16] and Dai-Ichi Life Research Institute[17] for real GDP respectively. The growth rates 2000 onwards followed the assumptions in Kibune and Kudo (1996).[18] The actual real GNP per capita for 1999 was available and was used for the forecasting. The real energy price was initially assumed to remain constant at the 1998 level. In addition, energy consumption was assumed to fall consistently by 0.39% p.a. due to the estimated downward underlying trend. The forecast results are shown in Table 4 and Figure 7.

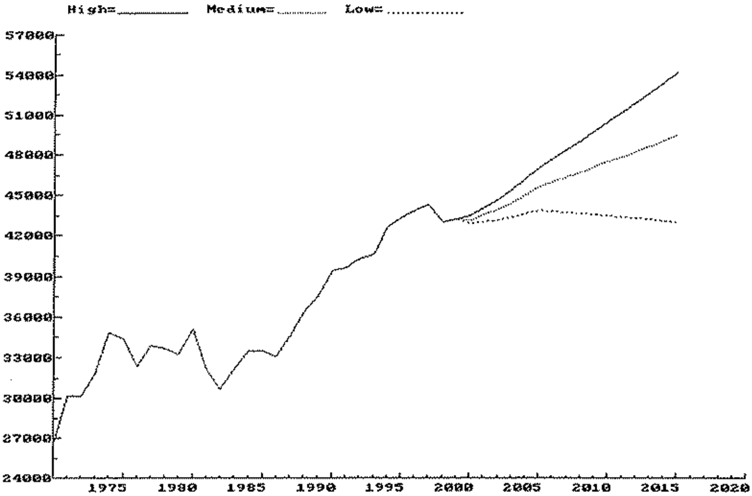
**Table 4: Forecast of primary energy consumption per capita in Japan 1999 – 2015 with constant real energy price at the 1998 level**

| | 1999 | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|---|
| Low growth case | 43,215 | 42,946 | 43,862 | 43,494 | 43,021 |
| Medium growth case | 43,215 | 43,194 | 45,627 | 47,529 | 49,468 |
| High growth case | 43,215 | 43,480 | 47,036 | 50,467 | 54,187 |

(1,000Kcal)

[15] *http://www.epa.go.jp/* downloaded on 15th September 2000.
[16] *OECD* (2000).
[17] *http://group.dai-ichi-life.co.jp/dlri/* downloaded on 15th September 2000.
[18] However, all of these assumptions are made for GDP rather than GNP and not per capita basis.

**Figure 7: Forecast of primary energy consumption per capita in Japan 1999 – 2015 (Constant real energy price) (1,000 Kcal)**




Note: 1. Low = low growth case, Medium = Medium growth case, High = High growth case.
2. Actual values are shown up to 1998.
3. Real energy price is held constant at the 1998 level for all cases.

In the low growth case, energy consumption per capita would remain around 43,000 Kcal over the forecasting period with an average growth rate of –0.03% p.a.. In 2015, it would be 43,021 Kcal which is 2.8% lower than the actual consumption of 44,273 Kcal in 1997.[19] In the medium growth case, energy consumption per capita would increase moderately at an average growth rate of 0.85% p.a. over the period. In 2015, it would be

[19] This is the record of the highest per capita primary energy consumption in Japan.

49,468 Kcal which is 11.7% higher than the 1997 level. In the high growth case, the energy consumption per capita would rise at an average growth rate of 1.42% p.a.. In 2015, it would be 22.4% higher than the 1997 level. Therefore, even in the high growth case, the energy consumption would increase at much lower rate compared to the actual growth of 2.2% between 1986 and 1998.

Under the Kyoto Protocol in 1997, Japan promised that its greenhouse gas (GHG) emissions, most of which is $CO_2$, will be 6% less the than 1990 level at 2008/2012 average. This is approximately 270 Million Carbon ton (Ct). It is well known that $CO_2$ emissions are closely related to the energy consumption. The ratio between them ($CO_2$ emissions per unit of primary energy consumption per capita) for the period from 1985 to 1997 gradually declined by 0.28% p.a. corresponding to the structural change in fuel-mix in primary energy use.[20] Taking into account this declining rate, average $CO_2$ emissions in 2008/12 were estimated to be 6.86 million Ct/Kcal primary energy consumption per capita, compared to the actual value of

[20] $CO_2$ emission data was taken from *EDMC* (1999).

7.11 million Ct in 1997.[21]

In the high growth case, $CO_2$ emissions would be 346.2 Ct at 2008/2012 average which is 28.2% higher than the Kyoto agreed level. Even in the low growth case, it would be 298.2 Million Ct which is still 10.4% higher than the agreed level. Hence, although relatively lower growth rate of primary energy was forecast for the next 15 years, associated $CO_2$ emissions are likely to grow much faster than the Kyoto Protocol agreement level even in the low growth case.

The above has assumed that the real price of energy will remain constant over the forecast period. It is of interest to examine possible impact of a pricing policy such as carbon taxation on energy consumption in order to reduce $CO_2$ emissions to the agreed level. Given the small absolute lower magnitude of the long-run price elasticity of energy demand found in the earlier section, a substantial increase in energy price would be required to further cutting energy demand. It is assumed in this case that the real

[21] $CO_2$ emissions are not per capita basis. Population is assumed to remain constant over the forecast period.

energy price will increase by 5% p.a. continuously throughout the forecasting period from 1999 to 2015. Table 5 reports the forecasting results for the each GNP growth case and Figure 8 shows the differences of forecasting projections between price constant cases and price rise cases.

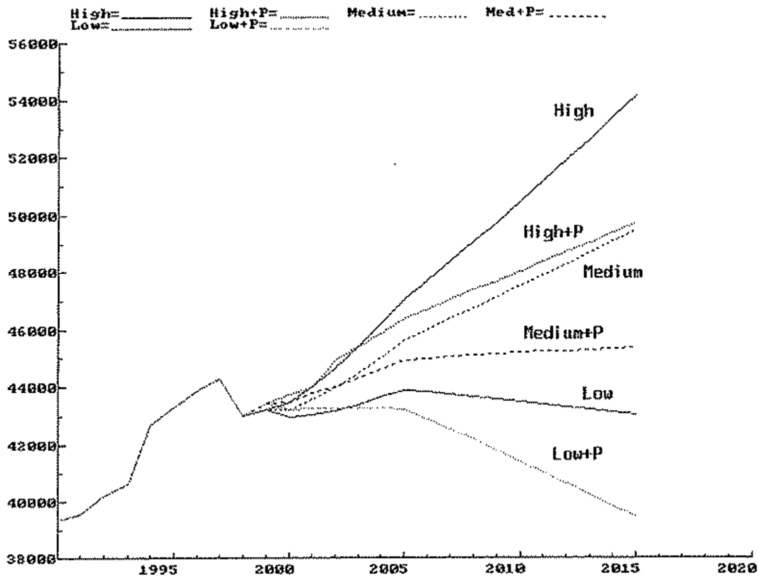
They show that, compared to the case of a constant real energy price, the energy consumption would be reduced by 1.5% in 2005, 4.9% in 2010, and 8.3% in 2015 in all GNP growth scenarios. Despite the impact of the price increase, the energy consumption would grow significantly if GNP growth is high. In the case of medium GNP growth, an increase in energy price would make the energy consumption being stable at around 45,000 Kcal. In contrast, if GNP growth is low, the energy consumption would substantially decline going back to the 1990 level in 2015 due to the price effect.

**Table 5: Forecast of primary energy consumption per capita in Japan 1999 – 2015 with real energy price increasing by 5% p.a.**

| | 1999 | 2000 | 2005 | 2010 | 2015 |
|---|---|---|---|---|---|
| Low growth case | 43,447 | 43,227 | 43,198 | 41,378 | 39,467 |
| Medium growth case | 43,447 | 43,477 | 44,937 | 45,216 | 45,382 |
| High growth case | 43,447 | 43,765 | 46,385 | 48,020 | 49,713 |

(1,000Kcal)

**Figure 8: Forecast of primary energy consumption per capita in Japan 1999 – 2015 (Constant and increasing real energy prices) (1,000 Kcal)**




Note : 1. Low = Low GNP growth case with constant price at 1998 level

2. Low + P = Low GNP growth case with energy price increase by 5% p.a. 1998 onwards.

3. Medium = Medium GNP growth case with constant price at 1998 level

4. Medium + P = Medium GNP growth case with energy price increase by 5% p.a. 1998 onwards.

5. High = High GNP growth case with constant price at 1998 level

6. High + P = High GNP growth case with energy price increase by 5% p.a. 1998 onwards.

7. Actual values are shown up to 1998.

With the price rise, associated $CO_2$ emissions would be 329.3 Million Ct, 309.9 Million Ct, and 283.7 Million Ct in the high growth, the medium growth and the low growth cases respectively. Unfortunately, even in the low GNP growth case, the $CO_2$ emissions would be still 5.1% higher than the agreed Kyoto level of 270 Million Ct. In reality, a 5% p.a. increase in real energy prise over more than ten years could be regarded as an extreme case and politically unacceptable. Hence, these results suggest that, given a tight relationship between GNP and energy demand and lower magnitude of price elasticity of energy demand, Japan needs a considerable effort to reduce energy consumption and $CO_2$ emissions in order to meet the agreed Kyoto levels; through governmental policies such as environmental regulation, R&D incentive, and education for energy conservation as well as pricing policy.

## VI CONCLUSION

This paper has examined the long-run linkage between energy demand, GNP, and energy price for Japan using annual data between 1887 and 1998. It is found that, if an underlying energy demand trend is appropriately incorporated, an econometric model produces long-run income elasticity of unitary and lower (in absolute term) long-run price elasticity of –0.15 with no signs of model mis-specification. This implies that there is a stable one-to-one relationship between energy demand and GNP over the last hundred years and, in contrast, the impact of the price changes is a lot smaller. The long-run linkage between energy demand and GNP is likely to continue, indicating that a substantial rise in energy demand may occur associated with higher growth in GNP in the future.

The underlying energy demand trend (UEDT) is found to be stochastic which is a non-linear inverse U-shape. Without this stochastic trend either by being restricted to be a conventional linear trend or by being completely ignored, the models were categorically rejected as mis-specified models. The underlying trend indicates that the economy was energy-using until the mid-1940s and turned into energy-saving after then. At the end of the sample period, the energy demand would fall by approximately 0.5% each year with GNP and energy price held constant. Driving factors of the trend may include technical progress, changes in economic structure and consumer's taste, and switching in energy resources. At this moment, the exact relationship between these factors and the trend pattern is rather obscure. Further research is needed to investigate this.

Using the preferred model, a forecast of primary energy consumption in Japan form 1999 to 2015 was then produced. The growth rate of energy consumption in the high GNP growth case was forecast to be on average 1.42% p.a. which is rather lower compared to the actual growth rate of 2.2% p.a. over the past 15 years. However, this growth would lead to 346.2 Million Ct of $CO_2$ emissions in 2008/2012 average, which is 28.2% higher than the Kyoto Protocol agreed level. Even in the low GNP growth case, it would lead to 10.4% higher $CO_2$ emissions than the agreed Kyoto level.

Possible effects of energy pricing policy on energy consumption was also examined using the same model. Certain impacts of the price rise on the energy demand were predicted. However, the forecasting results show that, even if GNP only grows by approximately 1.3% p.a., the real price of energy would need to increase by more than 5% p.a. in order to achieve the agreed Kyoto target.

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