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LONG-TERM PEAK ELECTRICITY LOAD FORECASTING IN TAIWAN: A COINTEGRATION ANALYSIS

TSER-YIETH CHEN

OCCASIONAL PAPER SERIES No.9604

December 1996

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TSER-YIETH CHEN[*]

Long-term Peak Electricity Load Forecasting in Taiwan: A Cointegration Analysis

Abstract

This paper utilizes a cointegration analysis approach to forecast Taiwan's long-term peak electricity load. We first divide peak load into base load, weather sensitive load, and load management conservation load, then predict individual loads respectively. We then use Johansen's maximum likelihood estimation procedure and obtain the long-term income elasticity for electricity. Finally, we establish an error correction model to find the short-term elasticity for electricity and forecast Taiwan's peak electricity load to the year 2010.

Key words: cointegration analysis, error correction model, peak load forecasting

I. Introduction

Since the energy resources of Taiwan are very poor, the fuel for

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electricity generation is dependent mostly on imported energy. There are three important reasons for peak load demand forecasting. An accurate peak load forecast is (i) the foundation of power plant planning, (ii) the basis for calculating the fuels' strategic reserve, and (iii) the core of utilities' demand-side management policy and implementation. In addition, due to the recent deregulation of Taiwan's power market, building a reliable peak-load demand forecasting system has become an urgent issue for government agencies. The information generated by the long-run load forecasting system will be used in national economic planning. The basic target is to maximize the efficiency of the utilization of costly imported energy.

In general, when we plan and forecast the system's peak load in the long term, we need to focus on the long-run relationship among the variables. Econometric studies in this field, i.e., (peak) load forecasting, include PG&E (1971), SCE (1981), Hagan and Behr (1987), Chang (1987), Tserkezos (1992), Chen (1993), CIER (1995), etc. Most of these papers estimate the income and price elasticity of load demand. Unfortunately, when we estimate such a long-run relationship using time series data, the variables used in the model are usually nonstationary and multicollinear. To solve this problem, the first difference of all variables is often taken. The result removes the long-run variation in the data and the difference model thus is only able to describe the short-run effects.

In this paper, we find that the variables used in the peak load function in Taiwan, e.g., base load, real income, the quantity of air conditioners, etc., are nonstationary processes. We then argue that the econometric model of peak load forecasting should be developed using cointegration analysis and the error-correction model (ECM). There are four reasons. First, cointegration analysis can properly catch the long-run relationship among the variables and solve the problem of nonstationary data. Second, the ECM model is able to distinguish clearly between short-run effects and long-run effects and estimate the elasticity in the short- and long-run periods. Third, the ECM model can also directly estimate the speed of adjustment towards the long-run relationship. Fourth, cointegration analysis and its related ECM model have a solid statistical foundation in the cointegration theorem and can effectively solve the problem of spurious regression.

The main objective of this paper is to employ cointegration analysis and the ECM approach to estimate short- and long-run elasticity of load demand in Taiwan. Then we utilize the estimated results to forecast future peak load up to the year 2010. The paper is organized as follows. This section and the next section form the introduction and literature review. Section three contains a brief description of our modelling procedure using a cointegration approach. It includes a four-step estimating procedure: unit-root test, cointegration vector estimate, development of an error-correction model, and the forecasting process. Furthermore, the empirical results for Taiwan's peak load forecasting are reported in section four. The estimated short-run and long-run income elasticity are also given in this section. The fifth section includes implications and concluding remarks.

II. Literature Review

The basic statistical assumption of the regression equation is that the variables are stationary stochastic processes (i.e., constant unconditional means and variances). Granger and Newbold (1974) proposed a spurious regression where a regression equation includes variable(s) with a nonstationary series. This model is also known as the random-walk model. They argued that the high coefficients of $\overline{R}^2$ and the t-value of the spurious regression will not represent the actual causal relationship. That is to say, the standard t statistic for this test does not follow a standard t-distribution. Rather, it becomes a function of Brownian motion. Many economic time-series are not well characterized as stationary processes (Nelson and Plosser, 1982). In fact, some economic variables are nonstationary series, which change stochastically over time and often driven by trends. In other words, they have a unit root in their autoregressive form. There are two types of nonstationary series: difference stationary process (DSP) and trend stationary process (TSP). The DSP is also called I(1) series because its nonstationary effect can be removed by making first differences. Similarity, TSP can be transferred to a stationary series by a detrend process. In this paper, we do not focus on the detrend method because the detrend method deals with the decomposition of the variable only and has proved less powerful in forecasting. The detrend method also focuses on a single variable case and cannot employ the multivariable situation. However, Pierce (1977) pointed out that the procedure of differencing nonstationary variables loses valuable long-run information (low frequency variation) within the data. It therefore can only explain the short-run effects and will bias the results when we employ the model to forecast long-run peak load.

Engle and Granger (1987) proposed a solution to the problem in terms of cointegration. They argued that we can find a linear combination which is a stationary series, I(0), to replace several nonstationary variables, I(1). When it works, we say the variables are cointegrated. When some variables are cointegrated, we can find a long-run relationship between them. The reason is that we can distinguish the trends of time-series data between deterministic and stochastic trends. The former is characterized as seasonal adjustment using dummy variables or cycled variation (it is deterministic seasonal). They do not drift too far apart from each other over time and thus there is a long-run equilibrium relationship between them. The latter is characterized as seasonal adjustment by stochastic seasonal differences. It will drift over time and represents a short-run dynamic effect.

Granger (1981) also indicated that a cointegration model can be represented by an error correction model (ECM). This is known as the Granger representation theorem. Engle and Granger (1987) suggested a two-stage estimation procedure. They suggested estimating the cointegration regression first and then estimating the short-run dynamics through variants of the error correction model using the estimated coefficient from the cointegration regression. Engle and Granger (1987) argued that an error correction model can effectively integrate the short-run dynamics with the long-run equilibrium to "correct" the problem of spurious regression.

Later, Schwert (1989) performed a Monte Carlo simulation and found that estimates of the cointegration regression are biased in small samples. The results invalidated the standard statistic inference procedure. In addition, we cannot obtain a unique cointegration vector with three variables or more because there may exist up to n-1 stationary linear relationships among n or nonstationary variables. Finally, Johansen and Juselius (1990, 1992) proposed a maximum likelihood estimation procedure to revise Engle and Granger's method. It is able to obtain a highly consistent estimator and satisfies the statistical property.

As to peak load forecasting, we discuss the following papers. First, Pacific Gas & Electric Company (1971) developed an exponential smoothing model to forecast peak load. Hagan and Behr (1987), Tserkezos (1992), and CIER (1995) then employed a Box-Jenkins model to capture the forecast short-run load demand. Southern California Edison (1975) and Chen (1993) established an econometrics model to forecast the system peak load which can provide a theoretical framework and give a causal explanation in the practical field. However, these studies are unable to cope with the nonstationary problem of the data. Therefore, Charleson and Weber (1993) utilized a vector autoregressive model to forecast the energy demand of Australia. Bentzen and Engsted (1993) also employed a similar model to forecast Denmark's energy demand. These are the original two papers that utilize cointegration analysis to forecast energy demand. However, there are no papers, as far as the author knows, which discuss the cointegration relationship in peak load forecasting. This paper therefore attempts to fill the gap in this field.

III. Modelling Peak Load Using Cointegration

The basic system peak load (PL) can be divided into two parts, i.e., base load (BL) and weather-sensitive load (WL), in order to include the economic and noneconomic factors, respectively. Base load represents the elementary load resulting from the regular economic affairs of the society. The main explanatory variables are income and electricity price which illustrate the derived demand of the economic system. However, electricity price in Taiwan is regulated by the government and the rate does not reflect the demand/supply of the power market. Some empirical studies in Taiwan, e.g., Chang (1987) and Chen (1993) argued that the electricity price is insensitive to load demand. Therefore, we omit electricity price and set up the base load model as follows:

$$BL_t = f(\underset{(+)}{Income})$$

Proxies for the income variable include GDP, per capita income (NI) and the index of industry production (IIP).

Weather-sensitive load describes the load derived from the variation in temperature. In Taiwan, the cooling load plays the major role in WL (weather- sensitive load) because Taiwan's system peak occurs in the summer. We thus establish the WL equation in this paper as the following:

$$WL_t = f(\underset{(+)}{Timing}, \underset{(+)}{Quantity})$$

The major explanatory variables of the WL are the time of air conditioner utilization and the quantity of air conditioners. WL is similar to the concept of "land area." It is equal to the product of the length (the use time of air conditioners) multiplied by the width (the quantity of air conditioners). Proxies for the use time of air conditioners are the cooling degree hours (CDH) and cooling degree Kwh (CDK). The former (CDH) is calculated by computing the total accumulated hours at 72 °F (28 °C) or above during the period of the peak month. The latter (CDK) is calculated by adding the total accumulated degrees at 72 °F(28 °C) or above. Furthermore, we can illustrate the behavior equation of the quantity of air conditioners (QAC) as:

$$QAC_t = f(\underset{(+)}{Income})$$

The quantity of air conditioners is influenced by the economic (income) level. Finally, we can add an adjustment item which is the reduction effect of load management (LML) to illustrate the demand-side management effect (DSM) to peak load.

In sum, the peak load equations estimated in this paper are the following:

$$PL_t = BL_t + WL_t - LML_t$$

and

$$BL_t = f(GDP_t \quad or \quad NI_t \quad or \quad IIP_t) \tag{1}$$

$$WL_t = f(CDH_t \quad or \quad CDK_t, \ QAC_t) \tag{2}$$

$$QAC_t = f(GDP_t \quad or \quad NI_t \quad or \quad IIP_t) \tag{3}$$

In this paper, the above equations are estimated in linear double-log form by least squares in order to directly find the elasticity coefficients. Note that equations (2) and (3) are obviously a recursive system. We can estimate the coefficients of equation (3) first, then estimate equation (2) by using the estimated results of equation (3). Therefore, we can estimate the above three equations individually.

We then develop a four-step procedure to forecast system peak load. First, we investigate the stationarity of all the variables by the unit root test. Second, if the variables in the same equations are found to be nonstationary but cointegrated, we employ the Johansen's maximum likelihood procedure to estimate the cointegration vector and long-run elasticity. Third, we utilize an error correction model to estimate the short-run elasticity and the speed of adjustment. Finally, we directly adopt the ECM model to forecast the future.

(i) Step one: unit root test

We first employ the augmented Dickey Fuller (ADF) test to conduct a unit-root test. The result of the ADF test is to examine whether the variable is integrated or stationary, i.e., I(1) or I(0). The core of the ADF test is to run the following regression function.

$$\triangle Y_t = \alpha + \beta Y_{t-1} + \sum_{i=1}^{p-1} \beta_i \triangle Y_{t-i} + rt + e_t$$

We include the $\triangle Y_{t-i}$ item in order to whiten the error terms. Next we test the hypothesis $H_o: \beta=0$ and/or r=0. If we do not reject the hypothesis, we can conclude that Y_t is a nonstationary random-walk series with unit root. In addition, we also conduct a Phillips-Perron (PP) test to run another regression:

$$\triangle Y_t = \alpha + \beta Y_{t-1} + rt + U_t$$

If we cannot reject the hypothesis, $H_o: \Delta Y_t = U_t$, we conclude that the series is a nonstationary process with unit root.

(ii) Step two: cointegration vector estimation

If the variables are shown to be I(1) processes by the unit-root test, the next step is to conduct a cointegration analysis to find a cointegration vector (linear combination). We apply a maximum likelihood estimation procedure developed by Johansen and Juselius (1990 and 1992) to reach the objective. The Johansen approach can also solve the problems discussed in section two. We consider a k-lag vector autoregressive (VAR) model:

$$X_t = \pi_1 X_{t-1} + \pi_2 X_{t-2} + \ldots + \pi_k X_{t-k} + e_t \tag{4}$$

The equation can be differenced into the following form:

$$\triangle X_t = S_1 \triangle X_{t-1} + S_2 \triangle X_{t-2} + \ldots + S_k \triangle X_{t-k} - \pi X_{t-k} + e_t \tag{5}$$

where X_t is a (px1) rank of I(1) variables, $\pi_1, \pi_2, \ldots, \pi_k$ are a (pxp) rank of coefficient matrices, and e_t is a (px1) rank error term. Therefore, we have:

$$S_i = -I + \pi_1 + \pi_2 + \ldots + \pi_i \text{ and } \pi = -I + \pi_1 + \pi_2 + \ldots$$
$$+ \pi_k (\forall i = 1,2,\ldots,k-1)$$

Then we can estimate the cointegration vector by the following steps. First, we regress $\triangle X_{t-i} (\forall i = 1,2,\ldots,T)$ on the $\triangle X_t$ and X_{t-1}, respectively. This provides two residuals, U_{ot} and U_{kt}. We then run the regression of

$U_{ot} = \pi U_{kt} + e_t$ and acquire a residual product moment matrix:

$$S_{ij} = N^{-1}\sum_{t=1}^{N} U_{it}U_{jt} \text{ , i. j = 0, k}$$

Next, we solve the eigenvalues $\lambda_1 \rangle \lambda_2 \rangle \ldots. \rangle \lambda_r \rangle 0$ from the equation: $\left|\lambda S_{kk} - S_{ko}S_{oo}^{-1}S_{ok}\right| = 0$ to calculate the eigenvector π. π is a cointegration vector.

(iii) Step three: develop an error-correction model

Equation (5) represents an error-correction model. It shows that we can "correct" the loss information from the long-run equilibrium via the error-correction item, πX_{t-k}. For example, in the case of a base load function, if there is a cointegration vector $[1, \beta]$ between $log(BL_t)$ and $log(GDP_t)$, we then develop the following error-correction model:

$$\Delta\log(BL_t) = a + b_1\Delta\log(BL_{t-1}) + b_2\Delta\log(GDP_t) + c(EC_{t-1}) + e_t \quad (6)$$

where $EC_{t-1} = \log(BL_{t-1}) + \text{constant-}\beta\log(GDP_{t-1})$. $\Delta\log(BL_t)$ is a function of lagged values of itself $(\Delta\log(BL_{t-1}))$, current and lagged values of explanatory variables ($\triangle$ log (GDP_t)), and an error-correction term (EC_{t-1}). Moreover, we can calculate the long- and short-run elasticity from the ECM model. The long-run elasticity is the estimated coefficient of the cointegration vector (e.g., β) and the short-run elasticity is the coefficient of the first-difference dependent variable (e.g., b_1). These results make the ECM model more attractive. We can also estimate the speed of adjustment toward long-run equilibrium. The coefficient of the error-correction item (e.g., **c**) represents its adjustment speed. The larger the value of **c**, the quicker the adjustment implied. We can conduct the OLS method and standard statistical inference method to estimate the coefficients of parameters of ECM because all parameters are stationary in the ECM. Noted that in this paper we have assumed BL_t is a dependent variable and GDP_t is an independent variable, thus we have only a single error-correction equation in the BL_t function.

(iv) Step four: forecast future load

We can easily forecast the future using the above ECM. For example, when we have estimated the coefficients of equation (6), we can calculate the figure of log (BL_{t+1}) using the following equation:

$$Log(BL_{t+1}) = a + (1+b_1)\log(BL_t) - b_1 \log(BL_{t-1}) + b_2 \log(GDP_{t+1}) - b_2 \log(GDP_t) + c(EC_t) \tag{7}$$

where the figure for GDP_{t+1} is obtained from exogenous variable forecasting. Finally, we can take the anti-log of log (BL_{t+1}) to calculate the figure for BL_{t+1} and we can further forecast the BL_{t+1} figure via the above recursive procedure.

IV. Empirical Results

This section reports the empirical results using the above estimating procedure. The data is from Taiwan Power Company and the Taiwan Statistical Data Book, and the time period ranges from 1963 to 1995. We then discuss the estimated results by equation.

Equation (1)

We first conduct the ADF unit-root test and PP test from the logarithmic form of each variable. In Table 1, we find evidence that log (BL_t), log(GDP_t) and log (NI_t) are nonstationary variables in the above two types of tests. However, log (IIP_t) is a I(0) series in the ADF test and a I(1) series in the PP test. Furthermore, if we difference the variables of the logarithmic form, all variables are stationary and integrated of order one. The above result implies that there may exist a cointegration relationship between the following two sets of variables: (i) log (BL_t) and log (GDP_t); (ii) log (BL_t) and log (NI_t).

We then employ the Johansen's maximum likelihood estimation

Table 1 Test of the Order of Integration

base load		ADF test			PP test		result
		including constant and time trend	including constant only	not including either	Zt	Za	
logarithm	BL	C(1.46) -1.1919 T(0.91)	-	3.4295	-1.3606	-2.5394	I(1)
	GDP	C(2.65) ** -2.6068 T(2.54)**	-	-	-2.3265	-9.9948	I(1)
	NI	C(3.12)** -3.0779 T(3.05)**	-	-	-2.7201	-12.761	I(1)
	IIP	C(2.37)** -1.0200 T(0.29)	-3.0658* C(3.96)**	-	-1.3564	-1.7501	I(0)
critical value(5%)		-3.5731	-2.9665	-1.9530	-3.4615	-20.4843	
critical value(1%)		-4.3082	-3.6752	-2.6453			
logarithmic first difference	BL	C(3.53)** -3.9150* T(-2.26)**	-	-	-4.8927*	-27.8064*	
	GDP	C(3.53)** -4.1043** T(-1.19)	-3.9051** C(3.65)**	-	-4.5615*	-23.3466*	
	NI	C(3.10)** -4.0297** T(0.54)	-3.0658* C(3.96)**	-	-4.5803*	-23.4954*	
	IIP	C(3.79)** -4.5476** T(-2.96)**	-	-	-5.3232*	-30.2788*	
critical value(5%)		-3.5796	-2.9705	-1.9535	-3.4615	-20.4843	
critical value(1%)		-4.3226	-3.6852	-2.6486	—		

weather-sensitive load		ADF test			PP test		result
		including constant and time trend	including constant only	not including either	Zt	Za	
logarithm	WL	C(5.23)** -4.2893* T(3.78)**	-	-	-7.9982*	-21.0305*	I(0)
	CDK	C(3.30)** -3.2999 T(1.15)	-3.1019* C(3.09)**	-	-6.0686*	-34.0159*	I(0)
	CDH	C(2.80)** -2.8009 T(0.41)	-2.8233 C(2.82)**	-	-3.2696	-19.7302	I(1)
	QAC	C(3.17)** -1.8693 T(1.62)	-1.9679 C(3.52)**	-	-1.5590	-4.0711	I(1)
	PWL	C(2.88)* -3.4728 T(-2.21)*	-	-	-3.3531	-15.4032	I(1)
critical value(5%)		-3.5731	-2.9665	-1.9530	-3.4615	-20.4843	
critical value(1%)		-4.3082	-3.6752	-2.6453	—		
logarithmic first differenc	WL	C(2.00)* -3.9433* T(-1.08)	-3.7842** C(2.28)*	-	-5.5063*	-31.6553*	
	CDK	C(0.16) -7.0468** T(-0.18)	-	-7.3509**	-13.9454*	-41.3066*	
	CDH	C(-0.12) -6.7310** T(0.08)	-	-7.0230**	-13.5492*	-40.8978*	
	QAC	C(3.18)** -3.8876* T(-1.62)	-3.4233* C(3.02)*	-	-4.8949*	-25.2224*	
	PWL	C(0.23) -3.5535 T(-0.27)	-	-3.6939**	-6.4004*	-34.2506*	
critical value(5%)		-3.5796	-2.9705	-1.9535	-3.4615	-20.4843	
critical value(1%)		-4.3226	-3.6852	-2.6486	—		

Notes The figures in parenthesis are the t-value of the constant or time trend regression coefficient, "*" shows significant at 5% confidence level and "**" shows significant at 1% confidence level, no unit root.

procedure to estimate a cointegration vector as follows: (i) log (BL_t)=0.7327 log (GDP_t); (ii) log (BL_t)=0.8917 log (NI_t), respectively (Table 2). For example, in the equation for log (BL_t) and log (GDP_t), we have calculated the statistic is 56.2972 (the p-value is 0.0002) and reject the hypothesis of the trace test $H_{01}: r = 0$ (no cointegration vector). On the other hand, we calculated the statistic as 2.7382 (p-value of 0.1089) and cannot reject the hypothesis $H_{02}: r \leq 1$ (one cointegration vector). That is to say, the long-run income elasticities of the base load are 0.73 (GDP) or 0.89 (NI), respectively. Note that we conclude that there exists one cointegration vector among the variables.

We then developed an error-corrected model shown in Table 3. We find that the short-run elasticities of income of the base load is 0.69 (GDP) or 0.70 (NI), which are both smaller than the long-run income elasticity given above, i.e., 0.73 (GDP) or 0.89 (NI). Moreover, we find that the sign of the error correction term is negative and the coefficient of the error correction term is -0.052 (GDP) or -0.058(NI). Both of them are correctly signed and have a reasonable magnitude. In other words, in case we are off the long-run demand curve, base load (consumption) adjusts towards its long-run level with about 5.2% (GDP) or 5.8% (NI) (of the adjustment) taking place within the first year. These results seem reasonable from an economic point of view. It is worth noting that we also can conduct an internal simulation by using the inequality coefficient of Theil--U_2.

$$\text{Theil-}U_2 = \left(\frac{1}{n}\sum_{i=1}^{N}(P_t - A_t)^2\right)^{\frac{1}{2}} \Big/ \left(\frac{1}{n}\sum_{i=1}^{N}(A_t - A_{t-1})^2\right)^{\frac{1}{2}}$$

where P_t is the current forecaster and A_t is the current observer. We further calculate the figure of Theil-U_2 of the error correction equation is 0.427 (GDP equation) or 0.490 (NI equation). This result implies that they have provided good forecast performance because the figures of Theil-U_2 are all lower than 1.

Table 2 Estimated Results of Cointegration Analysis

Items	**maximum likelihood procedure**			
	trace test		**eigenvalue**	**cointegration vector**
	$H_{01}: r = 0$	$H_{02}: r \leq 1$		
BL vs. GDP	56.2972	2.7382	0.8826	$\begin{bmatrix} 1 \\ -0.7327 \end{bmatrix}$
	0.0002	0.1089	0.1037	
BL vs. NI	54.7296	3.6836	0.8702	$\begin{bmatrix} 1 \\ -0.8917 \end{bmatrix}$
	0.0005	0.0559	0.1370	
PWL vs. CDH	15.9291	5.5878	0.3388	$\begin{bmatrix} 1 \\ -1.4302 \end{bmatrix}$
	0.0422	0.0178	0.2003	
QAC vs, GDP	62.2400	1.9441	0.9104	$\begin{bmatrix} 1 \\ -0.9526 \end{bmatrix}$
	0.0001	0.1850	0.0748	
QAC vs. NI	57.1971	2.4045	0.8883	$\begin{bmatrix} 1 \\ -1.1874 \end{bmatrix}$
	0.0002	0.1368	0.0917	

Notes: 1. BL: Base load; GDP: Gross domestic product; NI: per capita national income;
PWL: per air conditioner weather-sensitive load; CDH: cooling degree hour;
QAC: quantity of air conditioners. All figures are the logarithmic type.
2. In the trace test, the first column is statistics and the second column is p-value.

Table 3 Estimated Results of the Error-Correction Equations

$$1)\Delta \log BL_t = -0.0580 + 0.6907\Delta \log GDP_t - 0.0532\Delta \log BL_{t-1} - 0.0515EC_{t-1}$$

(-1.33) (3.98)* (-0.34) (-2.17)*

DW=1.76 RMSE=0.0323

$$2)\Delta \log BL_t = -0.0424 + 0.6996\Delta \log NI_t - 0.0659\Delta \log BL_{t-1} - 0.0580EC_{t-1}$$

(-1.20) (4.18)* (-0.42) (-2.70)*

DW=1.77 RMSE=0.0317

$$3)\Delta \log PWL_t = -4.4001 + 0.9799\Delta \log CDH_t + 0.2219\Delta logPWL_{t-1} - 0.4279EC_{t-1}$$

(-2.55)* (2.31)* (1.18) (-2.56)*

DW=1.85 RMSE=0.2840

$$4)\Delta logNO_t = -0.1584 + 0.0741\Delta logGDP_t + 0.0882\Delta logNO_{t-1} - 0.0457EC_{t-1}$$

(-1.02) (0.12) (0.43) (-2.13)*

DW=1.93 RMSE=0.1137

$$5)\Delta logNO_t = -0.1534 + 0.0768\Delta logNI_t + 0.0881\Delta logNO_{t-1} - 0.0454EC_{t-1}$$

(-0.99) (0.13) (0.43) (-2.19)*

DW=1.93 RMSE=0.1138

Note: The error-correction item is the logarithmic type.

Equation (3)

We find the log(QAC_t) produces a nonstationary variable integrated of order one. This shows that a cointegration relationship may exist between log(QAC_t) and log(GDP_t) as well as between log(QAC_t) and log(NI_t). Using the same procedure, we estimate the following cointegration vector: (i) log (QAC_t)=0.9526 log(GDP_t), and (ii) log(QAC_t)=1.1874 log(NI_t). This reveals that the long-term income elasticity of the quantity of air conditioners is 0.9526 (GDP) or 1.1874 (NI), respectively. Furthermore, we also derive that the short-term income elasticity of the quantity of air conditioners is 0.07 (DGP) or 0.08 (NI) from the error-correction model, which is substantially lower than their long-term elasticity given above. Again, the error-correction term is strongly significant with an adjustment speed of 4.4% (GDP) or 4.5% (NI) and the Theil-U_2 figures are 0.822 (GDP) or 0.715 (NI), respectively.

Equation (2)

First, we find that log(WL_t) is a I(0) series, no unit-root, whereas log(CDH_t) is a I(1) series. Because the order of the variables is different in equation (2), we cannot directly conduct an integration analysis. Therefore, we create a new variable: per air conditioner weather-sensitive load (log(PWL_t)), by dividing the weather-sensitive load into the quantity of air conditioners. The ADF test and PP test all show that log(PWL_t) is a I(1) process. The result implies that a cointegration relationship may exist between log(PWL_t) and log(CDH_t).

Again, we obtain a cointegration vector log(PWL_t)=1.4302 log(CDH_t), which reveals that the long-run elasticity of the cooling degree hour is 1.43. According to the ECM, we find that the short-run elasticity of the CDH is 0.98 and the speed of adjustment is 42.8%.

The detailed estimation and forecasting procedure is given as Figure 1. From Figure 1, we first estimate the future base load (BL_t) (A) from the error correction model of the base load. We also calculate the quantity of air conditioners and per air conditioner weather-sensitive load (QAC_t and

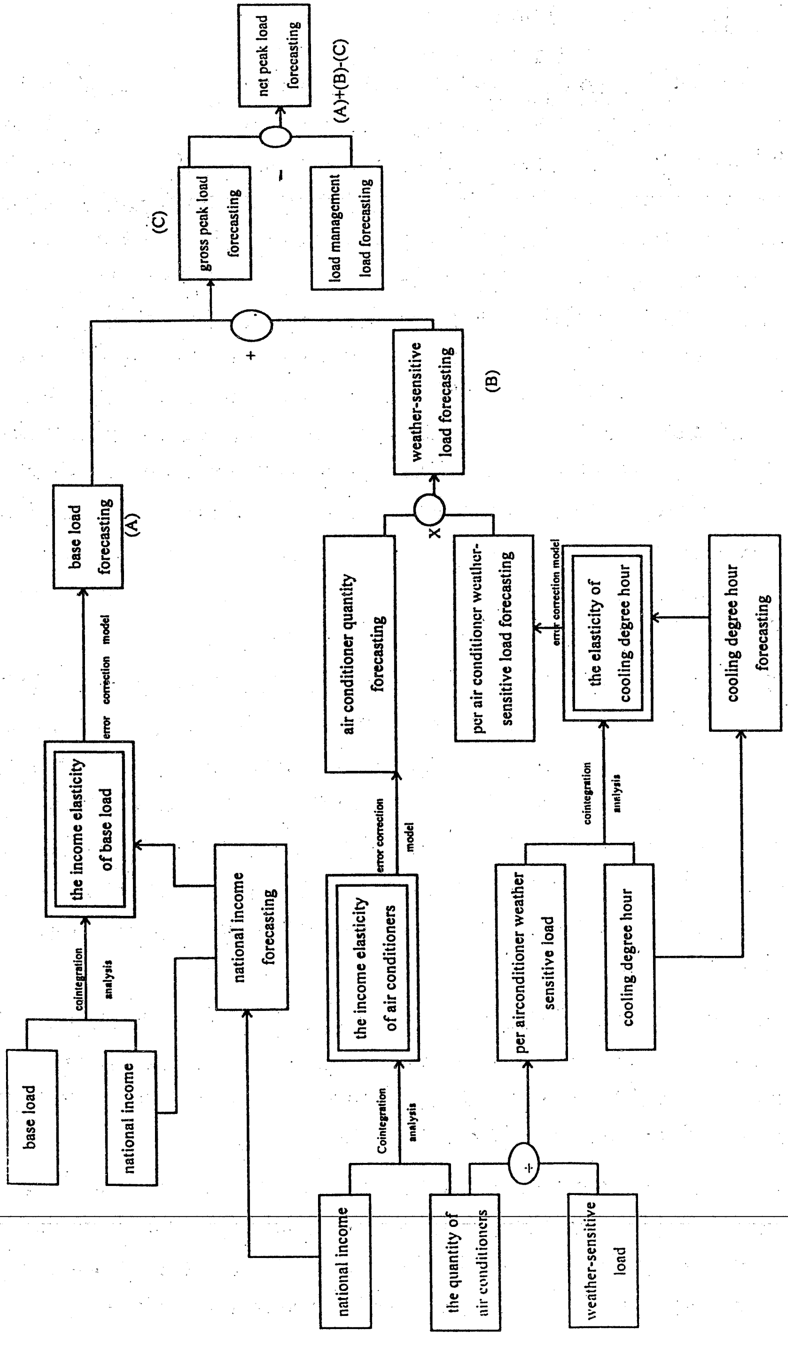

Figure 1 The Processes of Peak Load Forecasting

PWL_t) from their respective error correction model. We can then compute the multiplication of QAC_t and PWL_t to estimate WL_t (B). Finally, we can forecast the system peak load by directly calculating (A)+(B)-(C), where (C) is the forecast of DSM effects.

In the referenced scenarios, peak load is projected under the assumptions of moderate regulation of the energy sector and the influence of reducing CO_2 emissions, as well as under specific assumptions concerning high GDP growth and low GDP growth. GDP is assumed to grow at 5.8% from 1995 to 2001 and 5.2% per year from 2002 to 2010. The upper bound is 6.6% and 6.1% per year and lower limit is 5.1% and 4.5%, respectively. The estimated result shows that the average growth rate of the peak load in the next 16 years is 6.2%. The upper bound is 6.6% and the lower 5.8% (Figure 2). Among them, the base load will grow slightly (statically or slowly), with an average growth rate of 5.1%, whereas the weather-sensitive load will have strong demand, with an average growth rate of 8.3%. As to the effect of demand-side management, the average growth rate is estimated at 6.3%.

Note that the growth rate of the demand-side management load will decrease significantly. The reason is that DSM is a human-like effort and is similar to the behavior of coal digging. The marginal costs of load readjustment will increase gradually when we have adjusted most of the adjustable load. Utilities therefore need greater incentives to achieve the original target. Thus, we can expect that the effects of the DSM program will decrease. Finally, it is also noted that we have found that the oil crisis of 1973 caused no structural break in Taiwan's peak load. We can thus use the data simultaneously from both the ex ante and ex post oil crisis periods.

V. Concluding Remarks

We have employed cointegration analysis and the error-correction model to forecast the long-run peak load and estimate its short- and long-run elasticity. The short-run income elasticity of the base load is 0.69 (GDP) or

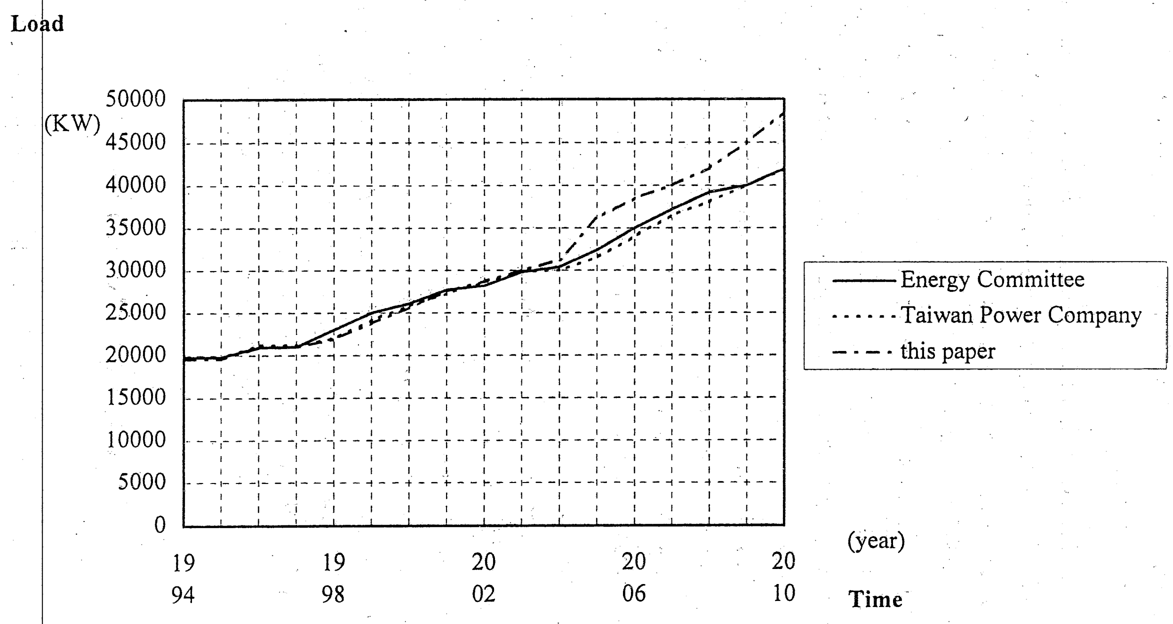

Figure 2 Comparison of the Estimated Results of Peak-Load Forecasting

0.71 (NI), which is smaller than that of long-run elasticity, i.e., 0.73 (GDP) or 0.89(NI). This also shows that if we are off the long-run load demand curve, the base load will adjust towards its long-run level, with about 5.2% (GDP) or 5.8% (NI) of that adjustment taking place within the first year. The estimated coefficients in the error-correction models have the expected signs and appropriate magnitudes which seem capable of forecasting peak load in the future. Under the assumptions of the real GDP growth rate published by the official plan, our estimated result of the future's average growth rate is 6.2% which is similar to, but represents a little higher trajectory for, future peak load from that stated by the Taiwan Power Company (5.2%) and the Energy Committee of the Ministry of Economic Affairs (5.3%).

Comparing our empirical results to other studies, the average growth rate in the next 16 years is 6.2%, which is higher than that forecasted by Taipower and the MOEA. The main difference is that the forecast in our paper indicates a stronger demand for weather-sensitive load, which will produce a higher peak load. The estimated result is reasonable for two reasons. First, because environmental quality has become worse, utilization of air conditioners will increase in order to isolate air pollution outdoors. This will increase the weather load effects. Second, people will install a second (or more) air conditioner in the same house as their income level increases. This will also amplify the amount of weather-sensitive load. In this paper, we also find that the share of weather-sensitive load to system peak load will increase gradually. The current share is 34% but will increase to 46% by the year 2010.

It is worth noting that there is a slight difference between base load and average electricity demand. The income elasticity of base load estimated by this paper therefore is not equal to the income elasticity of electricity demand. We thus find our estimated result, i.e., 0.73 (GDP) or 0.89 (NI), is closed to the unity which is typically found in the previous literature. It is also noted that structural changes in energy-intensive industry and the impact of global warming effects have been considered in the assumption of real GDP scenarios. We therefore do not need to modify the above estimated results if they have occurred.

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