

# A Dynamic Equilibrium of Electricity Consumption and GDP in Hong Kong: An Empirical Investigation\*

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First Version: July 2006  
Final Version: September 2006

## Abstract

Public debates on electricity policy in Hong Kong focus on the regulation regime but seldom discuss the macroeconomic impact. In this paper, we use the novel dataset on electricity consumption and report the following findings: (1) there is a long run equilibrium relationship between real GDP and electricity consumption, (2) a one-way causal effect exists from electricity consumption to real GDP, (3) a significant adjustment process occurs when equilibrium is interrupted, (4) there exists possible structural change in the relationship between electricity consumption and economic activities in 1990s.

**Keywords:** Cointegration and error correction; electricity; Hong Kong.

**JEL classifications:** Q41, Q43, Q48

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\*We thank Vivian Chiu, In Choi, Alex Ho, Michael Johnston, Mohitosh Kejriwal and an anonymous referee for helpful comments and suggestions. We are grateful to Hong Kong Institute of Monetary Research to compile and release the data. All remaining errors are our own.

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# 1 Introduction

In Hong Kong, developments in the market for electricity attracts much attention for policy debate. Most of the discussion focus on the regulatory regime (Cheng and Wu, 1998 and 2002) and, in particular, the Scheme of Control (Lam 1997 and 2004) on two investor-owned utilities: China Light and Power Company Limited (CLP) and the Hong Kong Electric Company Limited (HEC). These two utilities operate under a regulatory arrangement known as the Scheme of Control which includes both rate of return control and price control. The Scheme is a formal long term regulatory contract of 15 years which is signed between private firms and the Hong Kong Government to protect the producer's right to serve and the consumer's right to be served. Although internal efficiency is the main concern of the regulation, there are no studies of the relationship between electricity consumption and the economy with the exception of Lam and Ng (1994). They document a positive relationship between nominal GDP and total primary energy requirements during 1979-1991, but their results do not include any additional statistical tests. The objective of this paper is to show the importance of electricity consumption to output by establishing a statistical relationship between real GDP and electricity consumption in Hong Kong for the period from 1966 to 2002.

The contributions of this paper are twofold. First, it enriches the research initiated by Kraft and Kraft (1978) on the causal relationship between energy consumption and economic growth. They find a one-way causal effect from GNP to energy consumption in the United States. Yu and Choi (1985) and Erol and Yu (1987) extend the work to other industrial countries like the United Kingdom, Germany, Italy, Canada, France, and Japan. In subsequent studies, instead of relying on the standard Granger causality test, cointegration and error-correction models were used to address the issues of non-stationarity and simultaneity. Hwang and Gum (1992) provides the first investigation of the causal relationship between energy consumption and economic growth in Asian economies and Shiu and Lam (2004) provide a summary of recent research. In the case of Hong Kong, the economic structure changed dramatically during the sample period, it is interesting to know to what extent the relationship obtained in the literature still holds for Hong Kong. This paper first uncovers the statistical properties of the time series and determines the existence of a

long run relationship between real GDP and electricity consumption. Finally, we show that there is causality from electricity consumption to real GDP.

Second, this paper contributes to the literature investigating the impact of economic reform in China on the Hong Kong economy. Since China adopted the open door policy in the early 80s, Hong Kong has experienced a prolong period of outflow of manufacturing activities into China. Hsieh and Woo (2005) show that outsourcing from Hong Kong to China increased 2.7% annually from 1976 to 1996 which increased the relative demand for skilled workers. Tao and Wong (2002) document that the ratio of GDP share of service to GDP share of manufacturing increased from 3 in 1980 to 13 in 1997. Furthermore, the share of manufacturing in GDP decreased at 4.5% annually during 1990-1997. This transformation in the Hong Kong economy is due to the shift from manufacturing to producer service industries in business services, finance, import-export and insurance. These structural changes in economy can affect the relationship between electricity consumption and real GDP because the nature of electricity consumption by the services sector could be very different from that of the manufacturing sector. As argued in Chow (2001), the reduction in electricity use is due to the decline of manufacturing which relies on electricity for motive power, space conditioning and lighting. An economy becomes wealthier after transitioning into a service-based economy, and a higher level of income and saving stimulates the consumption of durable goods such as vehicles and electricity appliances in households. Our empirical results provide preliminary evidence of structural change in the relationship between electricity and output in that the response of output to electricity consumption is weakened in the second half of the 1990s. It indicates the transition to a service-based economy reduces the importance of electricity in economic growth.

The rest of the paper is organized as follows. The next section presents the empirical model. The third section discusses the data. In the fourth section we report the empirical findings. Finally, we conclude and discuss future research.

## 2 Model

### 2.1 Unit Root Test

To determine the time series properties of electricity consumption and real GDP, the Augmented Dickey-Fuller (1979, 1981) (ADF) unit root tests are applied to the natural logs of the data series.

The specification is

$$\Delta y_t = \alpha + \beta t + \mu y_{t-1} + \sum_{i=1}^p c_i \Delta y_{t-i} + \varepsilon_t \quad (1)$$

The error term is assumed to be independent and identically distributed. Dickey and Fuller (1981) proposed the Augmented Dickey-Fuller (ADF) test in order to handle the  $AR(p)$  process in the variables. Furthermore, we perform another unit root test proposed by Phillips and Perron (1988) (PP) which is based on the same equation as the ADF test but without the lagged differences. While the ADF test corrects for higher-order serial correlation by adding lagged difference terms to the right-hand side, the Phillips-Perron test makes a nonparametric correction to account for residual serial correlation without restricting the residuals to be white noise. Monte Carlo studies suggest that the Phillips-Perron test generally has greater power than the ADF test (see Banerjee, Dolado, Galbraith, & Hendry, 1993, p. 113 and Choi, 1992).

In Table 1, we report the test statistics. The lag parameter in the ADF test is selected by Akaike information criterion (AIC) to eliminate the serial correlation in residual. As shown in Table 1, the null hypothesis of a unit root cannot be rejected for both of the series at a 10% significance level. However, the unit root hypothesis is rejected for the first-differenced data. Therefore, we conclude that the series are integrated of order one.

### 2.2 Cointegration

Engel and Granger (1987) shows that if a long run equilibrium exists between two series, a linear combination of the non-stationary series can be stationary in which they are cointegrated. Since both series are integrated of order one, we employ the maximum likelihood test proposed by Johansen (1988) and Johansen and Juselius (1990) to test for the existence of cointegration. The procedure tests the null hypothesis of no cointegration against the alternative that there exists cointegration.

Since a long-run equilibrium can be represented as an additional error correction term in the VECM, the idea of the test is to look at the difference between the unrestricted model and the restricted model that imposes no error correction term by using a likelihood ratio test. The specification of our model is a 2-dimensional ( $2 \times 1$ ) vector autoregressive model with Gaussian errors that can be expressed by its first-differenced error correction form

$$\Delta y_t = \mu + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-i} + \Pi y_{t-1} + u_t \quad (2)$$

where  $Y_t$  is a  $2 \times 1$  vector containing  $[\log(\text{real GDP}), \log(\text{Electricity Consumption})]$ ;  $\mu$  is the  $2 \times 1$  vector of constant terms;  $\Gamma_i = -\sum_{j=i+1}^p A_j$  is the  $2 \times 2$  matrix of coefficients;  $\Pi = \sum_{j=1}^p A_j - I$  is a  $2 \times 2$  matrix of coefficients;  $u_t$  is a  $2 \times 1$  vector of the disturbance terms.

The  $\Pi$  matrix provides information about the long-run relationship between output and electricity consumption and the rank of  $\Pi$  is the number of linearly independent and stationary linear combinations of the variables studied. Therefore, testing for cointegration involves testing for the rank of  $\Pi$  matrix by examining whether the eigenvalues of  $\Pi$  are significantly different from zero. We employ two test procedures to test the number of cointegrating vectors or, equivalently, the rank of  $\Pi$  in the VECM model: the trace test and the maximum eigenvalue test. The likelihood ratio statistic for the trace test is

$$LR_{trace}(r|k) = -T \sum_{i=r+1}^k \ln(1 - \hat{\lambda}_i) \quad (3)$$

where  $\hat{\lambda}_i$  are the estimated  $2 - r$  smallest eigenvalues and  $r = 0$  and  $1$ . The null hypothesis is that there are at most  $r$  cointegrating vectors. The alternative is tested against  $r$  is larger than  $0$  or  $1$  respectively. On the other hands, the maximum eigenvalue test statistic is

$$LR_{max}(r|r+1) = -T \ln(1 - \lambda_{r+1}) \quad (4)$$

The null hypothesis of  $r$  cointegrating vectors is tested against the alternative hypothesis of  $r + 1$  cointegrating vectors. Thus, the null hypothesis  $r = 0$  is tested against the alternative  $r = 1$ , and  $r = 1$  against the alternative  $r = 2$ . Since the cointegration tests are sensitive to the choice of lag length, we use the AIC and adjusted log-likelihood to select the number of lags required to eliminate

the serial correlation in the residual. However, they provide different results on the lag selection. Thus, we test model (2) using a Lagrangian Multiplier test. The test suggests the lag length equal to 4 can produce residuals with no serial correlation from VECM model.

In addition to Johansen test, we use the residual based test for cointegration which assumes that there is no cointegrating relation between regressors. To test for the null of cointegration, we apply the test suggested by Shin (1994) and Choi and Ahn (1995) which applies the test of stationarity in Kwiatkowski et al (1992) to the residual from the following regression

$$y_t = \beta_0 + \beta_1 x_t + \varepsilon_t \quad (5)$$

where  $y_t$  and  $x_t$  are the natural logarithm of real GDP and electricity consumption, respectively. Our model is particularly suitable for this class of tests since we have only one regressor, which implies there is at most only one cointegrating relationship between regressand and regressor. If real GDP and electricity consumption are nonstationary, the residual of the regression between these two variables is stationary, and they are cointegrated. One advantage of using a residual based test is that we can investigate the movement of the residual to understand more about the relationship between real GDP and electricity consumption.

### 2.3 Dynamic Interaction and Causality

If real GDP and electricity consumption are cointegrated, there is causality between these two variables in at least one direction (see Granger, 1988). Engel and Granger (1987) propose that an error correction model can be used to test Granger causality for at least one direction. The model specification is as follows

$$\begin{aligned} \Delta y_{1t} &= \mu_{1t} + \sum_{i=1}^k \alpha_{1i} \Delta y_{1t-i} + \sum_{i=1}^k \beta_{1i} \Delta y_{2t-i} + \delta_1 Z_{t-1} + \varepsilon_{1t} \\ \Delta y_{2t} &= \mu_{2t} + \sum_{i=1}^k \alpha_{2i} \Delta y_{2t-i} + \sum_{i=1}^k \beta_{2i} \Delta y_{1t-i} + \delta_2 Z_{t-1} + \varepsilon_{2t} \end{aligned} \quad (6)$$

where  $y_1$  is the natural logarithm of real GDP,  $y_2$  is the natural logarithm of electricity consumption and  $\delta Z$  contains the cointegrating terms implied by the long-run relationship between these two variables. Interaction between these variables is captured by the coefficients of a lagged electricity

terms in the output equation, and vice versa. Short run causality can be tested through the joint test on all coefficients in the first-differenced VAR terms. More specifically, we use the following hypothesis

$$\begin{aligned} H_0 : \beta_{ji} &= 0 && \text{for all } i \\ H_1 : \beta_{ji} &\neq 0 && \text{for any } i \end{aligned} \tag{7}$$

for  $j = 1$  and  $2$ . In addition to the short run interaction, the VECM model provides the long run interaction between real GDP and electricity consumption through the coefficient estimate of the error correction term. If the error correction term is significant, adjustment will take place if the equilibrium relationship is disturbed. For example when electricity consumption is increased in a particular year, real GDP will adjust to restore the equilibrium relationship in addition to any short run impact of electricity consumption.

### 3 Data

All the data used are annual observations of the variables from 1966 to 2002. The electricity consumption is obtained from the Hong Kong Economic History Database which was recently released by the Hong Kong Institute of Monetary Research. The consumer price index (CPI) and nominal GDP are obtained from CEIC database. The units of electricity consumption and GDP are in Terajoules and millions of HKD, respectively.

## 4 Empirical Results

The paper investigates the relationship between real GDP and electricity consumption for Hong Kong from 1966 to 2002 by using the cointegration and VECM model. We found (1) there is a long run equilibrium relationship between real GDP and electricity consumption; (2) a one-way causality runs from electricity consumption to real GDP; (3) a significant adjustment process occurs when equilibrium is interrupted; (4) preliminary evidence of structural change in the long run equilibrium.

### 4.1 Long run Equilibrium

Evidence is found for the existence of a cointegrated relationship between output and electricity consumption in table 2. There is an empirical long run relationship between real GDP and electricity

consumption. The estimated cointegrating vector is  $\log(\text{real GDP}) = -1.59 + 0.94\log(\text{electricity consumption})$ <sup>1</sup> which indicates the long-run effect of electricity on real GDP is 0.94. Similar to other Asian economies, growth in the Hong Kong economy also depends on the expansion of the manufacturing sector. It explains the importance of electricity consumption to real GDP in Hong Kong since manufacturing is energy-intensive. Furthermore, Lam (1999) documents that the real electricity prices by CLP and HEC are decreasing over time. Using an endogenous growth model, van Zon and Yetkiner (2003) shows that when energy consumption is included as part of the input, the aggregate growth rate depends negatively on real energy prices. The drop in real energy prices increases the profitability of using new intermediate goods which have higher energy utilization rates and hence increases output. In equilibrium, the output is positively related to energy consumption.

## 4.2 Causality

Table 3 reports the causality tests. It shows that there is only one-way causality from electricity consumption to real GDP, but not from real GDP to electricity consumption. A one-way causality from electricity consumption to real GDP is a common empirical finding for many Asian economies. In searching for a possible explanation to this, it is helpful to notice that the manufacturing sector growth plays an important role in their development. Due to the fiscal restriction and policy adjustment processes, the infrastructure of electricity generation usually lags behind the growth of manufacturing sectors. Since shortages or instabilities in electricity supply would lead to interruption of production, firms take this into the account when scheduling their production. It acts as an capacity constraint for the production process in the short run. Most of the time, the production process uses less than the full capacity of facilities allowed and utilizes labor and physical capital as a substitute in production. When the government invests in the infrastructure to alleviate the bottleneck between electricity supply and demand, the production sector increases the usage for the electricity-demanding capital and hence increases output.

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<sup>1</sup>The estimated cointegrating vector is  $\log(\text{real GDP}) = -1.01 + 0.89\log(\text{electricity consumption})$ . The KPSS statistics is 0.134 where the critical value of 5% significant level is 0.146. We cannot reject the null at 5% significant level which confirms the existence of cointegration.

### 4.3 Dynamic Effect

The estimation results from the VECM model are shown in Table 4. The one-period lag of electricity consumption positively affects the output in the current period, whereas the two-period lag of output depresses contemporaneous electricity consumption. In order to assess long run effect of electricity on output, we compute the multiplier effect, which is 39% for output.<sup>2</sup>

Table 4 shows that the long run interaction is significant for both variables and the signs are as expected. The negative sign in the output equation indicates that when the output is higher than the long-run equilibrium between real GDP and electricity consumption, it cannot be sustained by the current usage level of electricity and needs to adjust downward to the equilibrium level. On the other hand, when the difference between output and electricity consumption is positive, there is a need for more electricity consumption in the long run and hence the electricity consumption adjusts upward. The adjustment speed is about 30% of deviation from equilibrium which implies a period of 3 years for adjustment. However, if we incorporate the lag structure of the endogenous variables then it reduces to 23% and 18% for real GDP and electricity consumption, respectively, which implies a 5 year adjustment process<sup>3</sup>.

The result is consistent with the implication in Atkeson and Keheo (1999). When there is a shock to induce higher energy consumption due to the drop in energy prices, firms adjust the intensity of energy use in capital goods in the production function. In the long run, it increases the elasticity of energy consumption with respect to price. Moreover, the output rises as the production process involves higher energy intensity.

### 4.4 Structural Change

Consistent with Chow (2001), Figure 3 shows that commercial electricity consumption surpasses industrial consumption in 1980. The electricity consumption in industrial sectors keeps increasing until 1990. It decreases and falls below the domestic household usage after 1993. The change of sectoral consumption in terms of total electricity consumption in Figure 4 illustrates a similar

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<sup>2</sup>Multiplier effect for real GDP is  $(0.650-0.288+0.294) / [1+(0.398-0.194+0.460)] = 0.656/1.664 = 0.394$ . Since there is only one-way causality, we compute the multiplier effect in this direction.

<sup>3</sup>Adjustment speed for real GDP is  $0.374 / [1+(0.398-0.194+0.460)] = 0.374/1.664 = 0.225$  and that for electricity consumption is  $0.331 / [1+(0.466+0.091+0.281)] = 0.331/1.838 = 0.180$ .

pattern. The change in the composition of electricity affects the relationship between real GDP and electricity consumption. Figure 5 plots the ratio of natural logarithm of electricity consumption over the natural logarithm of real GDP of Hong Kong. It shows a sharp decrease in the 1970s when manufacturing sectors were still dominating the electricity consumption of Hong Kong due to improvements in efficiency. However, the slope of the decline flattened out in 1980 when the commercial sector took over manufacturing sector and become the largest electricity consumption sector. Finally, the ratio shows a slight increase in the 1990s. The implication of the change in the economic structure on our results is shown in Figure 6, in which we plot the residual from model (5) over time. When we fit a regression of the residual on a constant term, year and year squared, we find the coefficients are all significant and there is a nonlinear relationship over time. The predicted residual is negative before 1972 and after 1995, which indicates that real GDP does not react as much as implied by the long-run relationship in the last decade. If the decreasing trend persists into the future, the current relationship between these two variables may be altered. Research on the possible change in the relationship between electricity consumption and output deserves further investigation.

## 5 Conclusion

In term of policy implications, the significant macroeconomic impact of electricity consumption on real GDP suggests the Hong Kong (SAR) government should be aware of the importance of stable electricity supply in the current negotiation of new regulatory terms in 2008 with the two Hong Kong electricity companies. The Hong Kong Government should strike a balance between maintaining the good corporate governance and ensuring a stable electricity supply in the future.

Nonetheless, the structural change in economic activities and the changing composition of electricity consumption in Hong Kong suggests a structural change between electricity consumption and economic activities may exist. Ignoring the structural break in the statistical analysis can lead to incorrect estimates and mislead in policy recommendations. In terms of future research, in Ho and Siu (2006), we are attempting to take into account the possibility of structural change in the long

run equilibrium and its effect on the causal relationship between GDP and electricity consumption.

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**TABLE 1: Unit Root Tests**

<i>Source of Causality</i>	<i>ADF</i>		<i>PP</i>	
	<i>Level</i>	<i>1st Difference</i>	<i>Level</i>	<i>1st Difference</i>
<i>Real GDP</i>	0.072 (2)	-4.039 (0)**	0.306 (3)	-4.051 (3)**
<i>Electricity</i>	-0.040 (0)	-3.278 (0)**	-0.160 (3)	-3.182 (3)**

Note: All variables are transformed to natural logs. The numbers in parentheses are the lag order in the ADF which is selected based on adjusted log-likelihood. The truncation lags are in the parentheses for PP test, which are Newey-West lags here, specified as  $\text{int}\{4^*(N/100)^{(2/9)}\}$  lags.

\*\* and \* indicate significance at the 5% and 10% levels respectively.

**TABLE 2: Johansen Tests**

<i>Eigenvalue</i>	<i>Trace Statistics</i>	<i>Max <math>\lambda</math>-Statistics</i>	<i>H<sub>0</sub></i>	<i>H<sub>1</sub></i>
0.359	18.97**	14.69**	No cointegration	At least 1 cointegration vector
0.122	4.28**	4.27**	1 cointegrating vector	At least 2 cointegration vector

Note: All variables are transformed to natural logs. The lag order 4 is selected based on the adjusted likelihood ratio. \*\* and \* indicate significance at the 5% and 10% levels respectively.

**TABLE 3: Causality Test**

<i>Source of Causality</i>	$\Delta Y$	$\Delta E$	<i>Null Hypothesis</i>
$\Delta Y$	-	0.17	$\Delta Y$ does not cause $\Delta E$
$\Delta E$	7.54**	-	$\Delta E$ does not cause $\Delta Y$

Note: \*\* and \* indicate significance at the 5% and 10% levels respectively.

**TABLE 4: VECM 1966 - 2002**

<i>Variable</i>	<i>Output Equation</i>		<i>Electricity Equation</i>	
	<i>Coefficient</i>	<i>se</i>	<i>Coefficient</i>	<i>se</i>
$\Delta Y_{t-1}$	0.398*	(0.229)	-0.076	(0.183)
$\Delta Y_{t-2}$	-0.194	(0.199)	-0.377**	(0.159)
$\Delta Y_{t-3}$	0.460**	(0.202)	-0.060	(0.162)
$\Delta E_{t-1}$	0.650**	(0.237)	0.466**	(0.189)
$\Delta E_{t-2}$	-0.288	(0.270)	0.091	(0.215)
$\Delta E_{t-3}$	0.294	(0.245)	0.281	(0.196)
$EC_{t-1}$	-0.374*	(0.201)	0.331**	(0.161)
<i>Constant</i>	0.008	(0.222)	0.009	(0.018)
$R^2$	0.782		0.894	
$N$	33		33	

Note: \*\* and \* indicate significance at the 5% and 10% levels respectively.

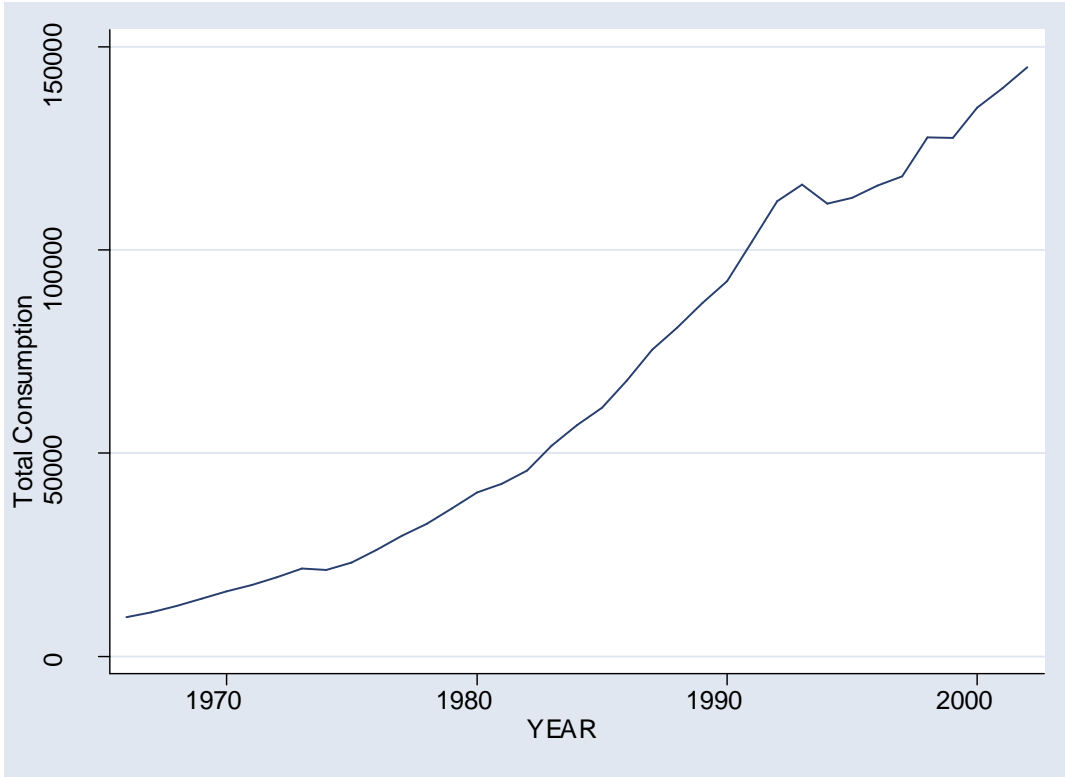


Figure 1: Electricity Consumption

Note: Unit is Terajoules; Sources: HKIMR.

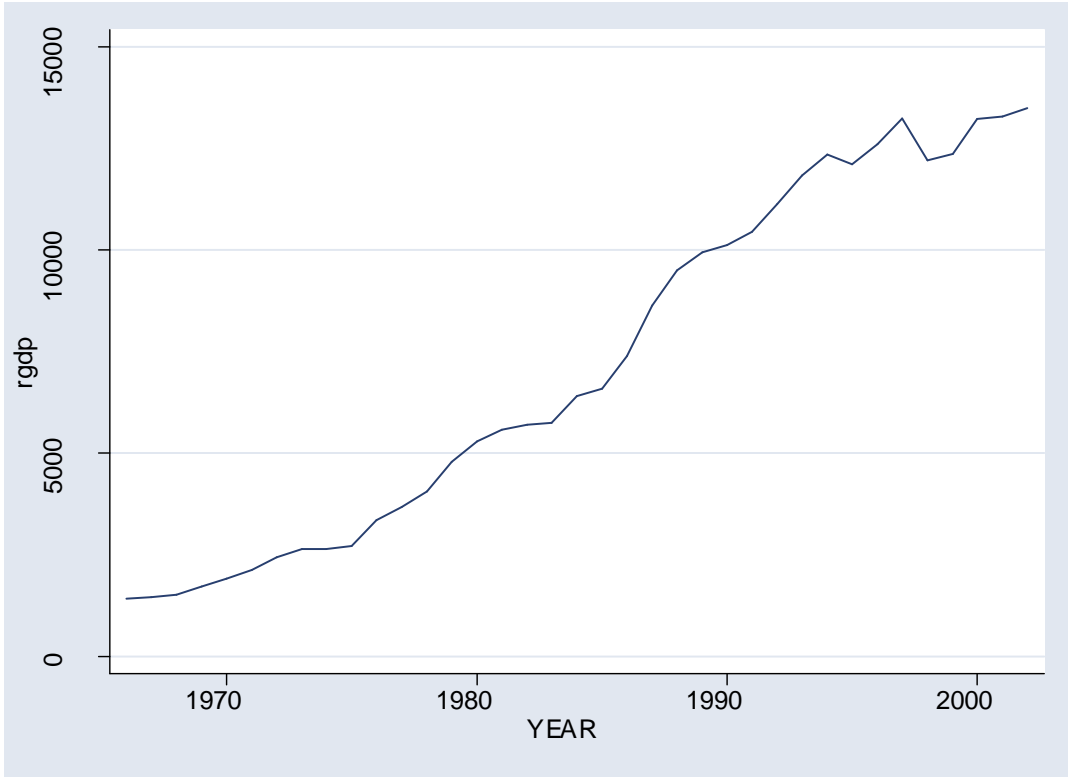


Figure 2: Real GDP

Note: Unit is millions of HKD; Sources: CEIC.

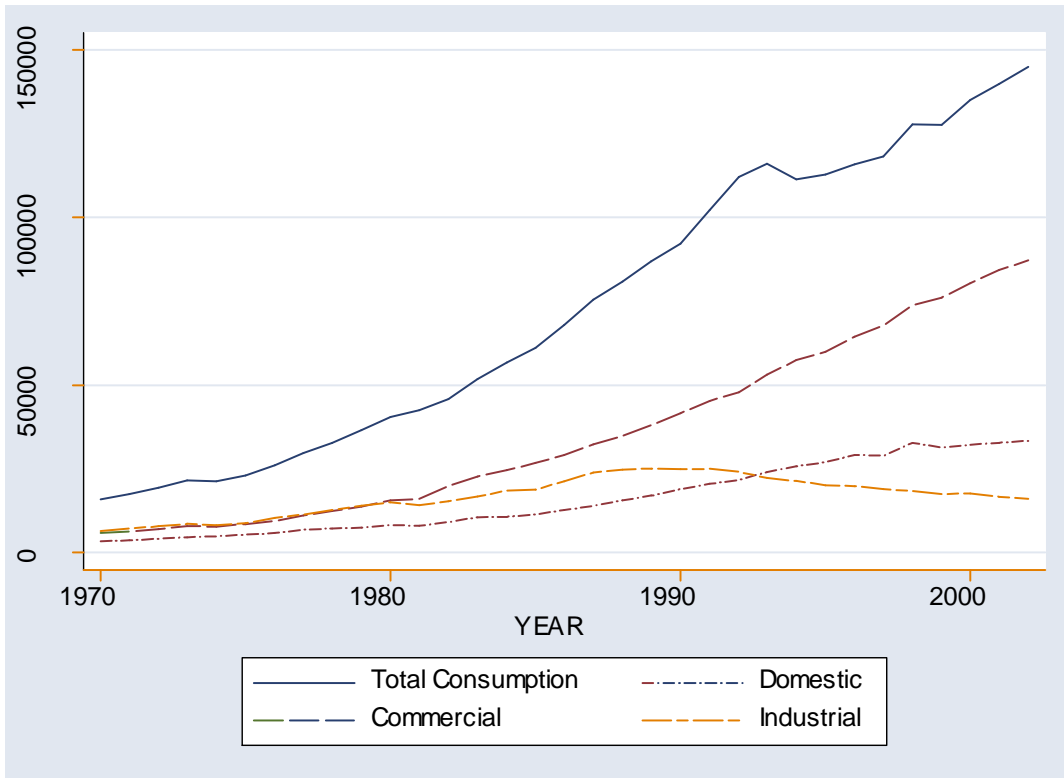


Figure 3: Sectoral Electricity Consumption

Note: Unit is Terajoules; Sources: HKIMR.

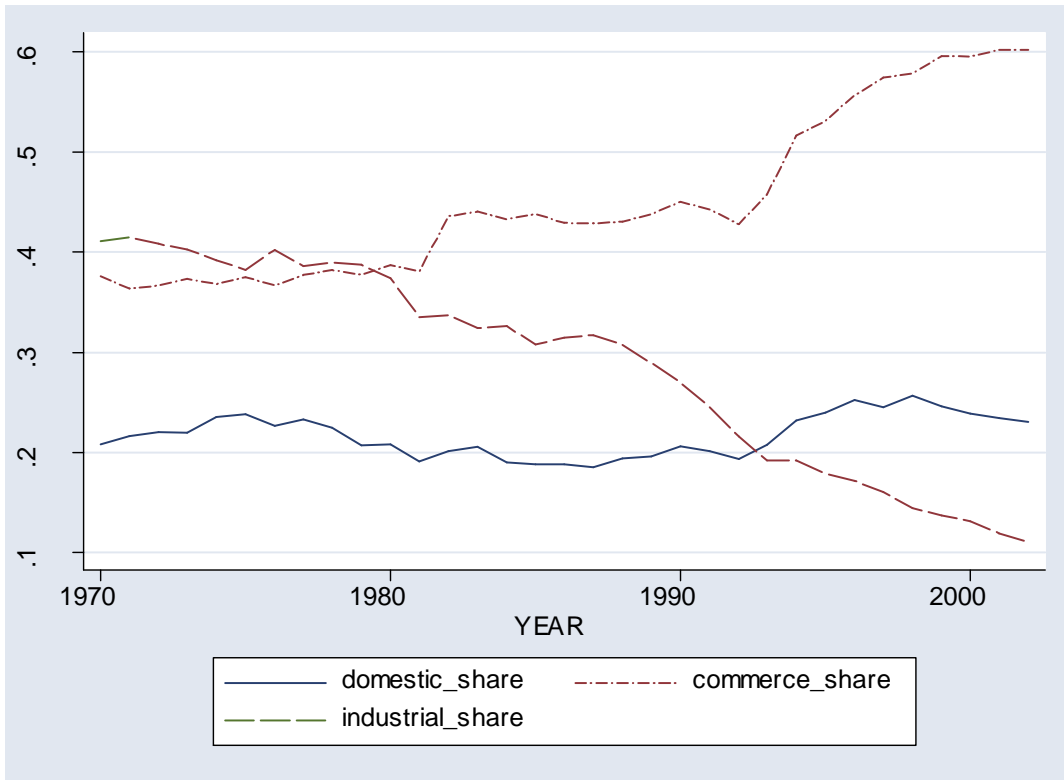


Figure 4: Share of Sectoral Electricity Consumption

Note: Sources: HKIMR.

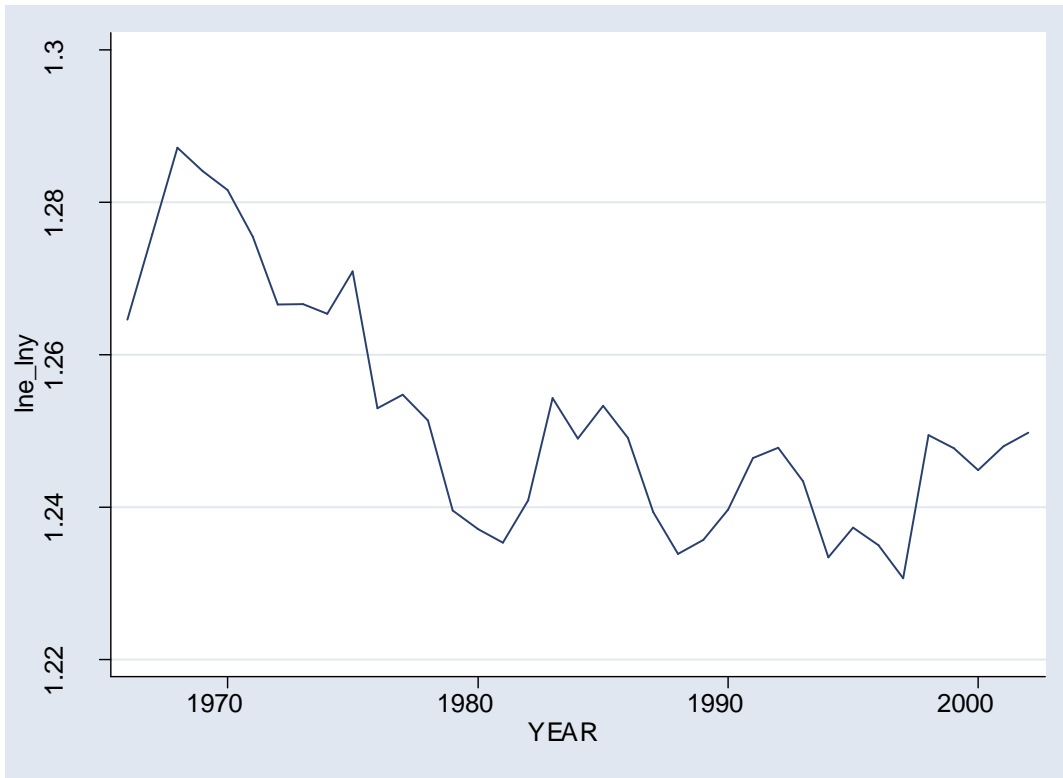


Figure 5: The ratio of  $\ln(\text{Electricity Consumption})/\ln(\text{real GDP})$

Note: Unit are Terajoules for electricity consumption and millions of HKD for GDP; Sources:

CEIC and HKIMR.

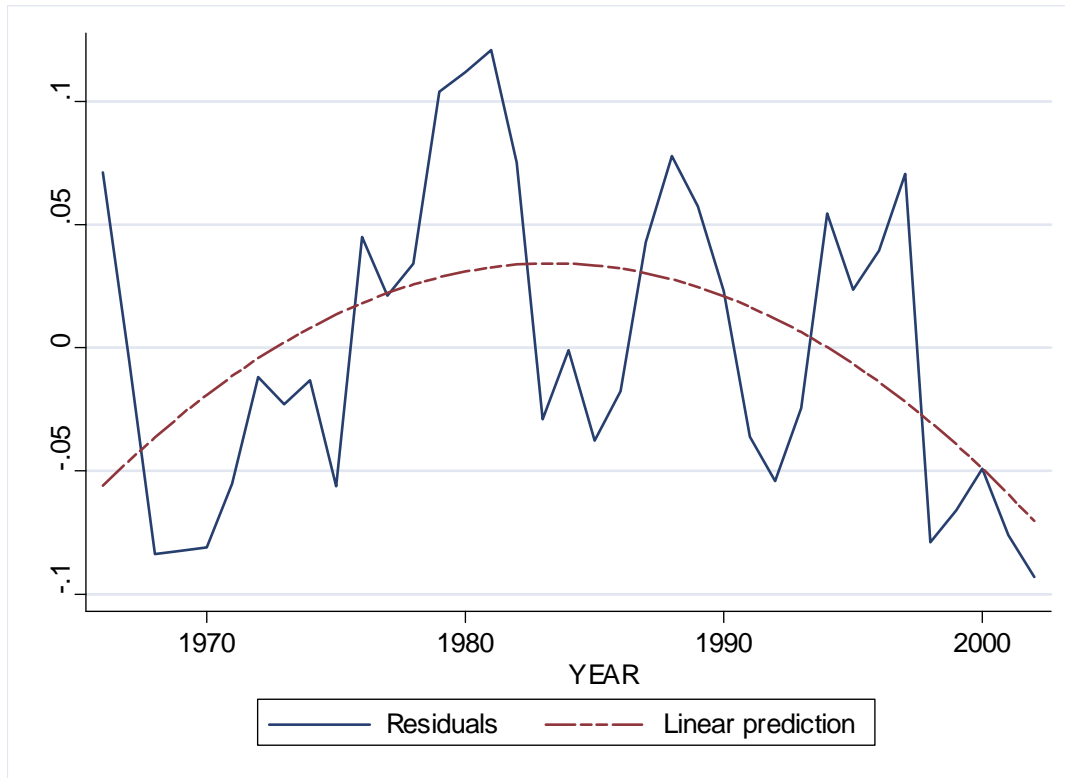


Figure 6: Residual of Equilibrium Relationship

Note: Solid line is the residual of  $\ln(\text{real GDP})$  regress on  $\ln(\text{Electricity Consumption})$  and a constant and the dotted line is the predicted value of the residual over time using constant, year and year<sup>2</sup>. Unit are Terajoules for electricity consumption and millions of HKD for GDP; Sources:

CEIC and HKIMR.