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An application of disequilibrium modeling to Taiwan

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Abstract

Using a disequilibrium model, we investigate the relationship between the supply constraint of electricity generation capacity and electricity demand in Taiwan. We find that electricity consumption faced supply constraints in Taiwan between 1959 and 1972, but that after 1973 generation capacity grew rapidly, such that economic growth came to be the major determinant of electricity consumption. Our experience in fitting this disequilibrium model suggests that simple causality tests are not a proper means to understand the relationship between electricity consumption and economic growth. Our results also suggest, at least for developing countries, that an electricity supply constraint sometimes plays an important role when investigating the relationship between energy consumption and economic growth.

Keywords: Electricity Supply; Economic Growth; Disequilibrium Model; Taiwan

JEL Classification: Q43, C34, O11

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1. Introduction

When considering the factors leading to economic growth in developing and middle-income countries, including Taiwan, the “export-led growth hypothesis” has been very influential. The basis of this hypothesis is that exports provide the engine for rapid economic growth. To investigate this, most studies apply Granger causality tests to time series data on GDP and exports, including in Taiwan (Chu 1988). As an alternative, to understand better the sources of economic growth, and following Kim and Lau (1994), we can instead estimate the national production function. We can then analyze the contribution of the separate factors in economic growth (so-called growth accounting) an approach taken by, for example, Hayashi and Prescott (2002) in explaining Japan’s Lost Decade. Sometimes, other explanatory variables are also included to control for the effects of other factors in the production function. For instance, Ghartley (1993) included the capital stock and terms of trade when investigating the export-led growth hypothesis. Electricity (or energy) consumption, the focus of this paper, is also an intermediate input, so the production function or growth accounting approach is also a candidate method when investigating the relationship between electricity consumption and economic growth

In terms of supply capacity or the constraints governing electricity, Rud (2012) recently analyzed the effects of electricity supply on local industrial development in India. This approach shed light on the fact that energy supply facilities, including electricity, are part of an economy’s essential infrastructure and that energy supply facilities therefore play an important role in countries aiming toward rapid economic growth. Some studies in Taiwan already focus on the impact of electricity supply capacity. Examples include studies providing long-term forecasts, such as Huang et al. (2011), and analysis of the demand structures for electricity across industrial sectors using input–output tables, including Chen and Wu (1994).

Following recent developments in time series analysis, most researchers first use unit root tests and then proceed to estimate long-run (cointegrating) relationships when investigating the relationship between energy or electricity demand and GDP. Soytas and Sari (2003), Chen et al. (2007), Lee and Chang (2008) and Ozturk et al. (2010) have applied this approach using data for a number of countries. At least some have also employed panel data analysis to analyze the long-run relationships across several countries. Of course, there are also many other studies that have applied this approach to the single-country case. For example, Nakajima (2010) analyzed regional electricity demand in Japan, Oh and Lee (2004) investigated the relationship between GDP and energy demand in Korea, and Hondroyiannis et al. (2002) examined the relationship between energy demand, the price level, and GDP in Greece. Elsewhere, Zachariadis and Pashourtidou (2007) analyzed the causal relationship between private income and residential electricity demand in Cyprus and Altinay and Karagol (2004) considered structural change when investigating the long-term relationship between GDP and energy consumption in Turkey. As for Taiwan, Yang (2000) analyzed the causal relationship between GDP and the consumption of coal, oil, gas, and electricity, while Holtedahl and Joutz (2004) focused on the relationship between urbanization and residential electricity demand. Following Yang (2000), Lee and Chang (2005) also considered structural change in the long-term relationships between GDP and various types of energy consumption, including coal, oil, gas, and electricity.

From an economics point of view, when we observe causality from GDP to energy or electricity consumption, economic growth effectively becomes a cause of the increase in energy or electricity supply. In other words, the supply of energy or electricity increases in response to economic growth. Conversely, when the causal relationship is from energy or electricity consumption to GDP, an abundance of energy or electricity induces rapid economic growth. By implication, a shortage of energy or electricity can equally serve as an economic growth bottleneck. The results of empirical studies on the exact direction of causality vary from country to country and study to study. For some countries, the direction of causality is from energy consumption to GDP, for others there is evidence of a reverse causal relationship, while for yet other countries, a feedback relationship is at play, suggesting bidirectional causality. As an example, recent work by Lee and Chang (2005) for Taiwan concluded that the causal relationship between GDP and energy demand is unstable in the long term and therefore it is difficult to identify causality clearly.

Besides these econometric analyses, Taiwan has been the subject of many economic history studies that emphasize the role of public enterprise in the early stages of economic growth following World War II. Above all, economic history studies by Japanese researchers, such as Kitaba (2003) and Minato (2011), conclude that the priorities of public companies in allocating electricity exerted a great effect on Taiwanese economic growth in the 1940s and the 1950s. In particular, Minato (2011, p. 223) declares that the complementary and well-developed relationship between the electricity-intensive industry and the electricity industry established in Taiwan in the late 1940s put Taiwan on the track to import substitution-led industrialization and rapid economic growth in the 1950s. Similarly, Kitaba (2003, p. 145) states "…the electricity always ran short until the 1980s when nuclear power plants started to work", he subsequently explains the economic benefits of low cost electricity (special contract electricity) (Kitaba 2003, p. 149), and how this system lasted up until 1976

(Kitaba 2003, p. 156). These accounts seemingly concur with the argument in Kuo and Myers (2012, p. 47): "From 1949 until the late 1950s, the administration was unable to generate adequate supplies of electrical energy…To supply energy at the low prices demanded by authorities and general population, high-cost electricity plants faced rapidly accumulating deficits."

If these historical details are correct, and the electricity supply was indeed a bottleneck for economic growth in Taiwan, the estimation of a simple electricity demand function will not adequately capture the relationship between electricity consumption, GDP and the price of electricity. For instance, when we investigate a causal relationship using Granger causality, if the electricity supply continued to be a bottleneck for economic growth, we may find a causal relationship from electricity consumption to GDP. However, if the times when electricity supplies had and had not been a constraint took place alternately, we could expect that the estimated relationship between GDP and electricity consumption would be unstable, and so the results of any time-series analysis would not correctly capture their actual relationship.

Following this discussion, we investigate the determinants of electricity consumption in Taiwan from 1950 to 2000 using a disequilibrium model encompassing both electricity demand and supply constraints. This model assumes that GDP and the price of electricity determine electricity consumption when there is sufficient supply capacity. However, when capacity is insufficient to meet electricity demand, electricity generation capacity determines electricity consumption. By estimating this type of disequilibrium model, we shed light on a dimension of the relationship between electricity demand and economic growth in Taiwan not captured through the estimation of a simple cointegration relationship.

The structure of the remainder of the paper is as follows. In Section 2, we first describe the relationship between electricity consumption and GDP in Taiwan after World War II. We also introduce and estimate a disequilibrium model to investigate the effect of a supply limit in electricity generation on Taiwanese economic growth. In Section 3, we summarize the results of the analysis and discuss some possible future research.

2. Empirical results

2.1 Taiwan's economic growth after World War II

Fig. 1 plots the trends in GDP and electricity generation capacity in Taiwan from 1949 to 2000. We describe the sources of the data in the following section. As shown, between the starting point in 1949 and the ending point in 2000, rates of change of GDP and generation capacity move up and down at various times and the lines intersect in about the middle of 1974.

Of course, the location of the intersection depends on the scales of the left and right vertical axes used plot GDP and generation capacity. However, we can appreciate clearly the differences in the changes in GDP and electricity consumption using this figure. This type of comparison is very similar to the energy coefficient method that Ang (1987, 1988) and Huang (1993) applied to the geometric mean of the growth rate of GDP and energy consumption in Taiwan.

With this in mind, the fact that the plot for electricity consumption crosses that for GDP from below in 1974 indicates that the growth rate of GDP is higher than that of electricity consumption in the first half of the sample period from 1949 to 2000 and vice versa in the last half of the sample period. In other words, the supply capacity of electricity may have been "tight" or reached some ceiling in the 1950s or the 1960s, whereas generation capacity may have become sufficient to meet electricity demand toward the middle of the 1970s and thereafter. To analyze such a situation with an econometric techniques, we have available so-called "disequilibrium models". In the next subsection, we introduce a disequilibrium model for electricity consumption.

2.2 Disequilibrium model

We first specify the demand and supply limit functions. In this analysis, a supply side restriction is not a supply function. We instead assume that there is a supply ceiling based upon generation capacity, so we specify the ceiling for supply as follows:

$$\ln \mathrm{C}_t = \ln \mathrm{S}_t = \alpha_0 + \alpha_1 \ln \mathrm{E}_t + \epsilon_t \quad when \;\; \mathrm{S}_t < \mathrm{D}_t$$
$$\epsilon_t \sim N(0,\ \sigma_2^2)$$

where E_t is generation capacity. As the equation is of log-linear form, $\ln \mathrm{C}_t = \ln \mathrm{S}_t$ infers that the supply of electricity equals the consumption of electricity. We include a normal error term ϵ_t as there may be observational errors or metrological disturbances in reported electricity consumption. As for the demand function for electricity, following the literature we specify real GDP (Y_t) and the electricity price (P_t) as independent variables, again in log-linear form:

$$\ln \mathrm{C}_t = \ln \mathrm{D}_t = \beta_0 + \beta_1 \ln \mathrm{P}_t + \beta \ln \mathrm{Y}_t + \mathrm{u}_t \quad when \;\; \mathrm{D}_t < \mathrm{S}_t$$
$$u_t = \begin{cases} \rho u_{t-1} + \omega_t & \text{when} \quad D_{t-1} < S_{t-1} \\ v_t & \text{when} \quad S_{t-1} \leq D_{t-1} \end{cases}$$
$$\omega_t \sim N(0,\ \sigma_1^2)$$

$$v_t \sim N(0,\ \sigma_1^2 + \sigma_{01}^2)$$

where $\ln C_t = \ln D_t$ indicates that the demand for electricity equals the consumption of electricity. We introduce a serially correlated error term in this function when the generation of the preceding observation is from the demand function and a serially uncorrelated error term when the preceding observation is set from the supply ceiling. These error terms have different variances, which we denote σ_1^2 and $\sigma_1^2 + \sigma_{01}^2$, respectively. In theory, if we assume serially correlated error terms, we should apply Quandt's (1981) estimation method. However, this method involves some limitations and difficulties when estimating parameters. Moreover, several market adjustments were made when demand faced a supply ceiling, and this served to lower electricity demand. We consider that these adjustments affected the error term for the demand function by removing any serial correlation but that it introduced a new serially uncorrelated error term when the ceiling became freer. In addition, if we apply Maddala and Nelson's (1974) estimation method, which does not utilize prior information about excess demand or excess supply to assign the observations *a priori* to excess demand or excess supply regimes, serially correlated error terms in the demand function make estimation difficult. Therefore, we utilize the ratio of electricity consumption to generation capacity to assign the observations to each regime:

$$\begin{aligned} t \in T_1 &: D_{t-1} < S_{t-1} \quad \text{when} \quad \frac{C_t}{E_t} > k_0 \\ t \in T_2 &: S_{t-1} \le D_{t-1} \quad \text{when} \quad \frac{C_t}{E_t} \le k_0 \end{aligned}$$

where k_0 is unknown and so we estimate it using a grid search method to maximize the likelihood and introduce the following dummy variable:

$$Dum_t = \begin{cases} 1 & \text{when} \quad t \in T_1 \\ 0 & \text{when} \quad t \in T_2 \end{cases}$$

in each k_0. The model is now the same as Model B in Quandt (1988, p. 22) with a serially correlated error term in the demand function. Then, the likelihood function for each observation becomes as follows:

$$\mathrm{l_t{=}Dum_t}^*\frac{1}{\sqrt{2\pi\left(\sigma_1^2+(1\text{-}\mathrm{Dum}_{t\text{-}1})^*\sigma_{01}^2\right)}}$$

$$\times \exp\left(-\frac{1}{2}\frac{\left(\ln C_t\text{-}\beta_0\text{-}\beta_1\ln P_t\text{-}\beta\ln Y_t\text{-}\mathrm{Dum}_{t\text{-}1}{}^*\rho^*(\ln C_{t\text{-}1}\text{-}\beta_0\text{-}\beta_1\ln P_{t\text{-}1}\text{-}\beta\ln Y_{t\text{-}1})\right)^2}{\sigma_1^2+(1\text{-}\mathrm{Dum}_{t\text{-}1})^*\sigma_{01}^2}\right)$$

$$\times\left(1-\Phi\left(\frac{\ln C_t-\alpha_0-\alpha_1\ln E_t}{\sigma_2}\right)\right)$$

$$+(1\text{-}\mathrm{Dum}_t)^*\frac{1}{\sqrt{2\pi\sigma_2^2}}\exp\left(-\frac{1}{2}\frac{(\ln C_t-\alpha_0-\alpha_1\ln E_t)^2}{\sigma_2^2}\right)$$

$$\times\left(1-\Phi\left(\frac{\ln C_t\text{-}\beta_0\text{-}\beta_1\ln P_t\text{-}\beta\ln Y_t\text{-}\mathrm{Dum}_{t\text{-}1}{}^*\rho^*(\ln C_{t\text{-}1}\text{-}\beta_0\text{-}\beta_1\ln P_{t\text{-}1}\text{-}\beta\ln Y_{t\text{-}1})}{\sigma_1+(1\text{-}\mathrm{Dum}_{t\text{-}1})^*\sigma_{01}}\right)\right)$$

where $\Phi(*)$ is the cumulative density function of the standard normal distribution and the likelihood function for the observations becomes:

$$L=\prod_{t=1}^{T} l_t\ .$$

We maximize this likelihood function to estimate the parameters with k_0 given and then search for that k_0 which maximizes the likelihood for a given k_0 between 3055 and 3557. The lower bound is equal to the mean while the upper limit for convergence in the estimation process for maximum likelihood estimation determines the upper bound.

2.3 Data and estimation

Table 1 provides the sources and definitions of the data used in the estimation. As shown in Table 1, we calculate the nominal price of electricity by dividing total electricity sales by the volume of electricity sold. We then obtain the real price by deflating this estimated nominal price by the GDP deflator at 1960 prices. Fig. 2 depicts the estimated real price of electricity obtained using this method. As shown, the real electricity prices increased temporarily in the 1980s, outside of which the overall trend was gently increasing with relatively small increases and decreases. In Table 2, we provide summary statistics for the logs of each data series.

Table 3 provides the estimation results obtained using the maximum likelihood method. The standard errors of the equations for the supply constraint and demand function and the estimated coefficients are significant at the 1% level of statistical significance with the exception of the estimated coefficient for GDP in the demand function and the increase in the standard error of the demand function following the resolution of the supply constraint. The estimated coefficient for GDP is significant at the 10% level using a two-sided test. When we consider the expected sign of the coefficient and apply a one-sided test in a positive direction, the estimate for GDP is statistically significant at the 5% level of significance.

As for the increment in the standard error of the demand functions following the resolution of the supply constraints, we estimate this to be ten times more than that without increments. However, and as discussed later, because we had only two observations (1961 and 1973) with which to estimate this value between 1950 and 2000, the estimate of the parameter is not stable. We estimate the ratio of electricity consumption to generation capacity, which determines whether the supply constraints held or not, to be between 3.360 and 3.397. We obtained this result using a grid search with integer values between 3.055 and 3.557 to maximize the likelihood. When we set the ratio between 3.360 and 3.397, the separation of the period whether the supply constraints are present or not is the same and the estimation result for the disequilibrium model given by the maximum likelihood method is unchanged between these ratios. Because of space limitations and in the interests of brevity, we have not conducted the unit root and cointegrating relationship tests usually found in previous studies in this area. However, we do employ a test for cointegrating relationships using McKinnon's (1991) table concerning the coefficient of the lagged residual from the estimated demand function. The calculated test statistic for the unit root in error terms becomes:

$$z = \frac{\hat{\rho}-1}{\sqrt{Variance(\hat{\rho})}} = -4.996.$$

Given the number of independent variables (N = 3) and the sample size (T = 50) in our analysis, the calculated critical value at the 5% significance level is:

$$\hat{C}(p,T) = \hat{\beta}_{\infty} + \hat{\beta}_1 T^{-1} + \hat{\beta}_2 T^{-2} = -3.7429 - 8.352/50 - 13.41/(50)^2 = -3.9153.$$

Given the test statistic is smaller than the critical value, we consider that the estimated demand function does not represent spurious regression. Of course, this is not an exact testing procedure for this type of disequilibrium model, but it can be considered as a rough approximation.

2.4 Estimated regimes and relationship between the supply ceiling and demand

In Fig. 3, we illustrated the ratios of actual electricity consumption and the estimated electricity supply ceiling given by the supply limit function. The shaded regions in Fig. 3 represent periods when electricity demand reached the ceiling. As shown, it is clear that with the exception of 1961, between 1959 and 1972 the supply ceiling held. As discussed earlier, the observation points used to estimate the increase in the standard error following the resolution of the supply constraints comprise only two time points: 1962 and 1973. After 1973 and until 2000, the last year of our estimation period, electricity consumption did not reach the supply ceiling. This suggests that electricity generation capacity was not a constraint to economic growth in Taiwan after 1973. This result is somewhat different from Kitaba's (2002) earlier findings that electricity shortages persisted in Taiwan up until the 1980s. However, until 1972, we consider that electricity consumption had reached the ceiling of supply and so some sort of restriction on economic growth in Taiwan must have existed.

Compared with existing studies employing the estimation of cointegrating relationships and the use of causality tests, our result suggests that we should identify a causal relationship from electricity consumption to GDP up until 1973, while after 1973 we would instead identify a causal relationship from GDP to electricity consumption. Were we to consider structural change within the sample period, we would locate it in 1973 and it would be associated with a change in the direction of causality. On this basis, we argue the finding in Lee and Chang (2005), of difficulty in identifying a clear cause-and-effect relationship between GDP and electricity consumption in Taiwan, is the result of the regime switching we found by fitting a disequilibrium model.

3. Conclusion

Using a disequilibrium model, we investigate the relationship between the supply constraints of electricity generation capacity and electricity demand in Taiwan. Between 1959 and 1972, electricity consumption faced supply constraints, but after 1973, generation capacity grew rapidly such that economic growth came to be the major factor in determining power consumption in Taiwan. Fitting this disequilibrium model suggests that applying simple causality tests is not a proper approach for understanding the relationship between electricity consumption and economic growth in Taiwan. Our analysis therefore provides a meaningful economic interpretation for the historical changes in the relationship between economic growth and electricity consumption in Taiwan, which has hitherto been a "black box" in the estimation of the long-term relationship and causality tests using time-series model in existing studies. This result also provides evidence that the econometric approach (disequilibrium model) used in this paper can play a complementary role to conventional time series analysis. It also suggests that, at least in developing countries, that electricity supply constraints sometimes play an important role in determining the relationship between energy consumption and economic growth.

As a final matter, we note some problems remaining in our analysis, all of which suggest future directions of research. To start with, in estimating our disequilibrium model, the splitting of the estimation period according to the regime switch makes it difficult to conduct unit root tests and to test for cointegrating relationships because of the shortened time series. In addition, we cannot stably estimate the standard error for the demand function after the regime switch. At present, there is no means available to improve this situation and thereby provide a more robust estimation method, but we trust that novel analytical methods or models to address these deficiencies will be available in the future.

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Table 1. Data Sources

Data	Definition	Source
Revenue from electricity sales	Revenue from electricity sales in New Taiwan Dollars	Tai Power's home page (access at /07/02/2013/) http://www.taipower.com.tw/content/govern/govern01.aspx?MType=8
Consumption of electricity	Sales of electricity in kWh	Tai Power's home page (access at /07/02/2013/) http://www.taipower.com.tw/content/govern/govern01.aspx?MType=8
Price of electricity	$\frac{\text{Revenue from sale of Electricity}}{\text{Consumption of electricity}}$	Authors' calculations
Capacity	Electricity generation capacity in kWh	Tai Power's home page (access at /07/02/2013/) http://www.taipower.com.tw/content/govern/govern01.aspx?MType=8
Real GDP	Aggregated real GDP (in 1960 prices). Estimated using two alternative methods before adjustments for discrepancies in GDP/GDE	Table 7.2 on p. 327 in Mizoguchi (2008)
Nominal GDP	Aggregated nominal GDP before adjustments for GDP/GDE discrepancies	Table 7.1 on p. 325 in Mizoguchi (2008)
GDP deflator	Nominal GDP/Real GDP	Authors' calculations

Table 2. Summary Statistics

Variable	Definition (before logarithmic transformation)	Mean	Standard Deviation	Minimum	Maximum
lnC	Consumption of electricity	23.19329	1.53603	19.97254	25.2747
lnP	$\frac{10000 \times \text{Price of electricity}}{\text{GDP deflator}}$	8.71225	0.20094	8.37213	9.14169
lnY	Real GDP	12.45521	1.26746	10.3897	14.49585
lnE	Capacity	15.18123	1.52278	12.527	17.20445

Table 3. Estimated Results

Variables	Demand function		Supply limits	
	Coefficient	t-value	Coefficient	t-value
Constant	22.8999	7.165**	–	–
lnP	–0.2472	–5.983**	–	–
lnY	0.3597	1.721+	–	–
ρ	0.9623	127.693 **	–	–
σ_1	0.0397	10.630**	–	–
σ_{01}	1.6714	1.471	–	–
Constant	–	–	8.2038	23.370**
lnE	–	–	0.9989	40.906**
σ_2	–	–	0.0388	3.382**
log likelihood	81.1492			
k_0	[3360 , 3397]			

Note: ** and + indicate statistical significance at the 1% and 10% level, respectively.

Log-likelihood reported from the results of the ML command in TSP 5.0.

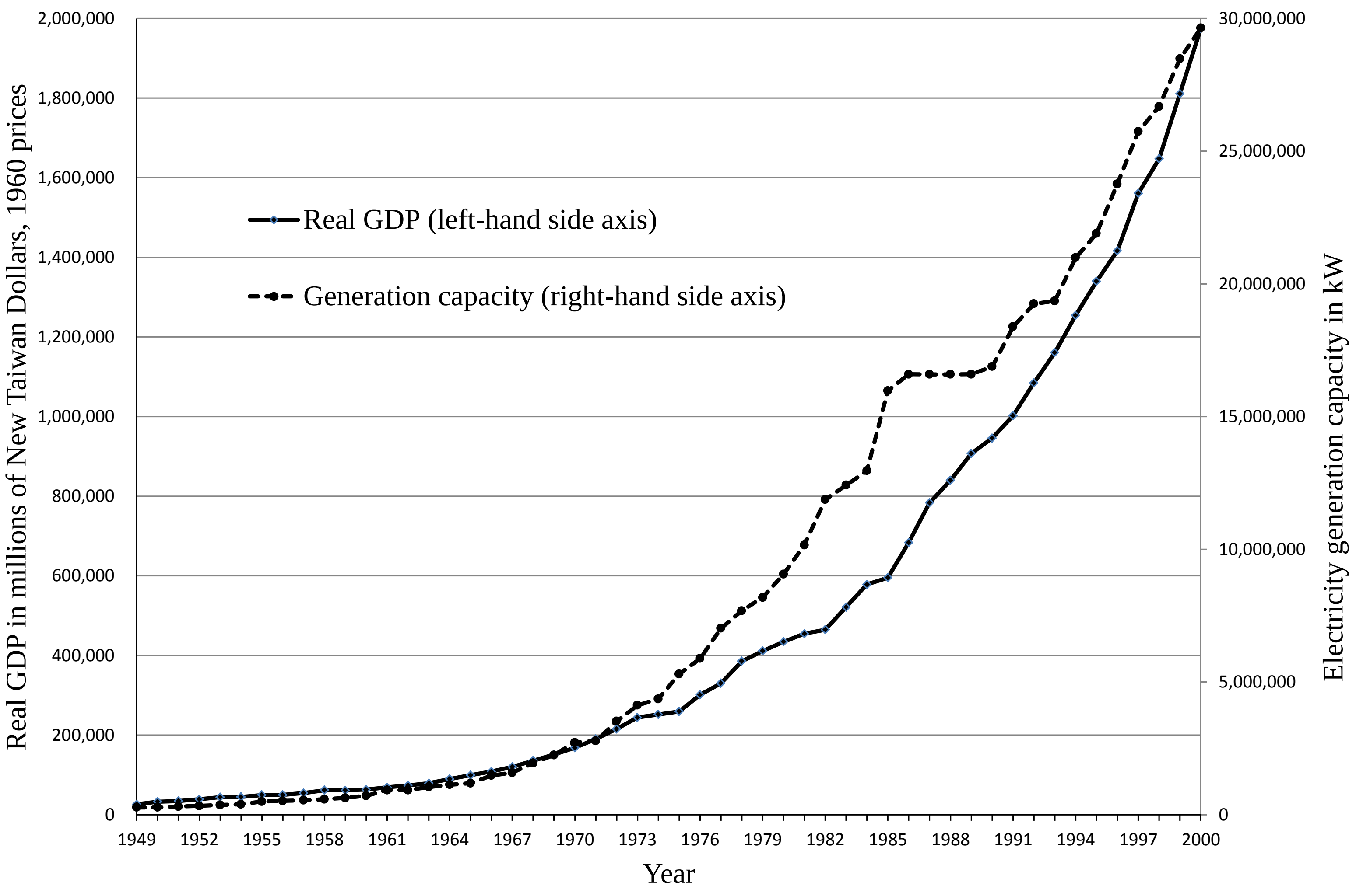

Fig. 1 Trends in Real GDP and Electricity Generation Capacity

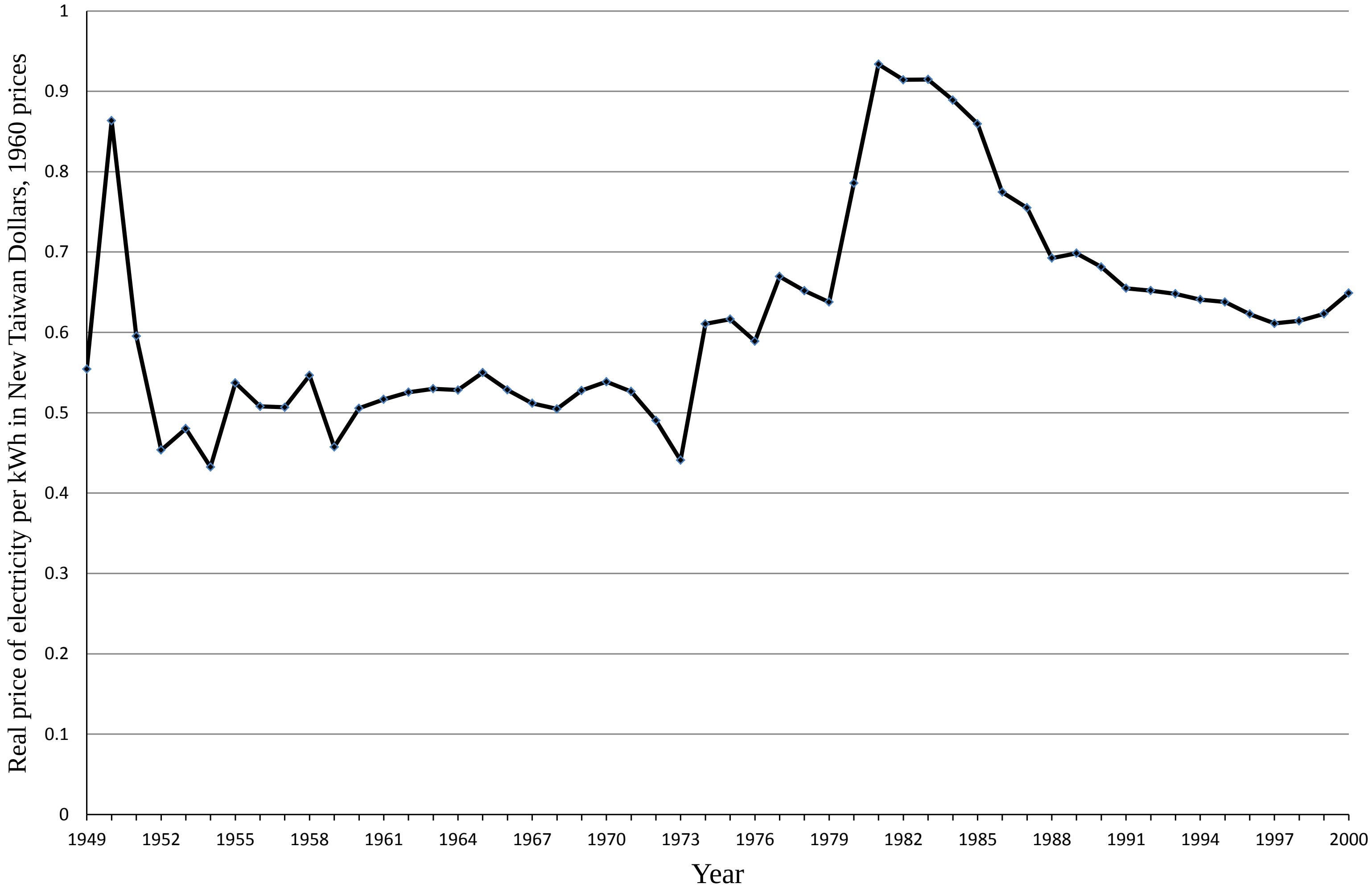

Fig. 2 Price of Electricity

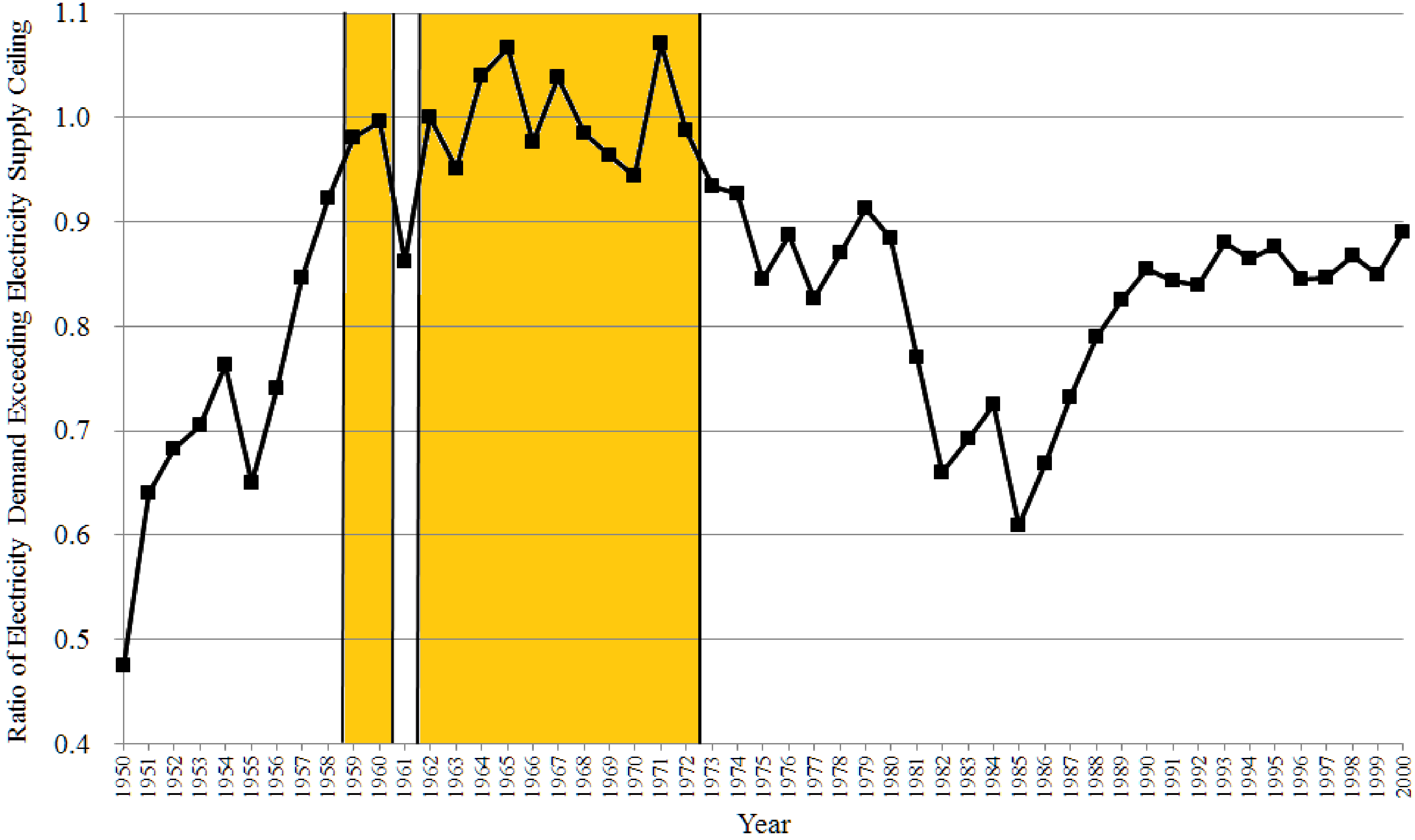

Fig. 3 Electricity Demand Exceeding Electricity Supply Ceiling