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Foreword

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Abstract

This paper uses a macroeconomic approach to develop a long-run electricity demand model to analyze the main factors affecting electricity demand in the People's Republic of China (PRC). As expected, the relationship among variables is more stable and significant after the PRC's economic reforms (1978), when all factors were more responsive to market forces. An error correction model provides an appropriate framework for forecasting the short-run fluctuations in aggregate electricity demand. The demand elasticity of gross domestic product (GDP) is estimated at about 0.8 after the 1978 economic reforms, lower than that of the pre-reform period (before 1978). The results show that although GDP is still the most important factor for electricity demand, electricity demand is negatively related to structural changes and efficiency improvement. This implies that in a fast growing economy such as the PRC, high GDP growth does not always come with high electricity demand and explains why in 1998, when the PRC had an economic growth rate of 7.8 percent, electricity consumption grew by only 2.8 percent. To meet the forecasted demand growth, the total install capacity incremental is estimated to be 187 GW between 2002-2010, while the required investment costs are estimated to be US$193 billion in 2002 prices. The continued growth of coal-fired power plants will increase the share of the power sector in total sulfur dioxide emission from 50 percent in 2001 to 53 percent in 2005.

I. INTRODUCTION

The People's Republic of China (PRC) is the second largest electricity producer in the world after the United States. By the end of 2001, the installed capacity was 338 gigawatts (GW) and annual electricity generation was 1,446 terawatt-hours. Thermal power contributes about three quarters of the installed generating capacity, hydropower about one quarter, and nuclear power about 1 percent. During 1985-1995, annual average growth in electricity consumption was 9.1 percent, slowing to 7.4 percent in 1996, 4.8 percent in 1997, and 2.8 percent in 1998. However, electricity consumption grew by 6.1 percent in 1999 and by 9.2 percent in 2000. About 98 percent of the nation's villages and 97 percent of the rural population have access to electricity. This impressive achievement was part of the rapid economic growth in the PRC (about 8 percent annually) and the result of government efforts to reform the energy and power sector.

In the last two decades, demand for electricity has been increasing more rapidly in the PRC than anywhere else in the world (averaging 9 percent annually) and is expected to continue growing. To meet rising demand, the PRC must address such issues as how to meet the resulting enormous capital requirements and how to prevent environmental deterioration. A good understanding of electricity demand will help calculate what the capital requirements may be, and to estimate potential environmental impact.

The theoretical study of demand forecasting of electric power systems started in the mid-20th century. Before that, because the scale of power systems was limited, the study of demand forecasting had not taken shape. It was not until the 1980s that the theoretical study of medium- to long-term electricity demand forecasting began, and a series of forecasting methods, such as autoregressive (AR) algorithm, moving average (MA) algorithm, general exponential smoothing algorithm, autoregressive-moving average (ARMA) algorithm, and autoregressive integrated moving average (ARIMA) algorithm began to be successively developed and widely accepted in electricity demand forecasting of power systems, particularly in developed countries (Zhang Chun 1987). The increasing desire to obtain reliable forecasts is not only for power utilities but also for governments, because of its impact on economic growth and environmental protection. The reliability and confidence levels associated with these forecasts are more crucial in fast-growing areas experiencing a phenomenal growth in electricity demand. The confidence levels associated with classical forecasting techniques, when applied to forecasting problems in mature and stable power systems, are unlikely to be similar to those of dynamic and fast-growing utilities. In general, it is more difficult and challenging to forecast electricity demand in a fast-growing economy, where structural changes could have a significant impact on electricity demand. This is attributed to differences in the nature of growth, socioeconomic conditions, occurrence of special events, and subsidized energy tariffs (Baraket and Eissa 1989). However, it is possible to ascertain the accuracy, suitability, and credibility of established classical forecasting techniques while searching for more improvements by taking into account the nature of growth, socioeconomic conditions, occurrence of special events, and subsidized energy tariffs.

According to the definition of a demand function, electricity demand, in general, is determined by some main factors including gross domestic product (GDP), prices, and population. This paper, by analyzing the specific social and economic conditions in the PRC, introduces structural changes and efficiency improvement variables into electricity demand forecasting. Further, in contrast to previous papers, this study is based on two increasingly popular econometric techniques, namely, unit root test and cointegration model (Engle and Granger 1987). The reasons for adopting these advanced approaches in estimating electricity demand are twofold. First, earlier econometric studies on electricity/energy demand have been subject to spurious regression (Greene 2000), which arises when variables that are driven by time trends appear to be correlated in finite sample regression, even though no true relationship exists among them. Second, since the economic variables employed in the electricity demand equation, such as GDP and tariff, are likely to be endogenous, estimating electricity demand by a single equation may produce simultaneous bias and hence lead to unreliable forecasts. Both problems can be overcome with the help of the cointegration model. The cointegration technique could especially identify the long-term equilibrium relationship among variables, if they exist.

So far, there is no empirical test of the aggregate electricity demand in the PRC in the economic literature. This has led to some misunderstanding in calculating GDP elasticity for electricity consumption.[1] Further, the current econometric models forecasting electricity demand at provincial levels usually include only GDP, electricity prices, and population growth as the main variables. This paper attempts to fill the gap by incorporating the impact of structural changes and efficiency improvement on electricity demand.

Accurate projection of electricity demand is a precondition for successfully implementing power system planning, which in turn will have significant impact on future GDP growth. Since the GDP growth rates were 8.8 percent in 1997 and 7.8 percent in 1998, the low electricity demand growth rates of 1997 (4.8 percent) and in 1998 (2.8 percent) have raised some doubt on the stable relationship between electricity demand and GDP. Some even doubted the accuracy of GDP growth figures in these years. This paper, by analyzing stability of the relationship between main macroeconomic variables and electricity demand, attempts to provide a rational explanation for the 1997-1998 phenomen.

Section II introduces the factors affecting electricity demand, establishes demand function, and discusses data sources. A detailed discussion on econometric analysis and results is presented in Section III. In Section IV, major developments in the power sector that might cause demand

[1] For example, Wu (2002) calculated a GDP elasticity of 0.84 in 1995, 1.37 in 2000, and 1.15 in 2001 using the formula electricity growth rate/GDP growth rate.

fluctuations in the short to medium term are evaluated. Section V introduces a short-run error correction model. Section VI presents estimates on the capital requirement to meet the forecasted demand and the environmental impact due to incremental power supply. Section VII provides the paper's conclusions.

II. FACTORS AFFECTING ELECTRICITY DEMAND AND DATA SOURCES

In general, electricity demand is mainly determined by two important factors, tariff and GDP. This is a general accepted definition of demand function. In a modern economy, electricity is a necessary input in the production process and people's daily activities and is not an ordinary good. Electricity is bought for the end-use service it provides. As a result, a number of important and sometimes countervailing factors change the pattern of electricity demand (Gellings 1996). Therefore, factors affecting economic activities and consumption patterns will have an important impact on electricity consumption.

There could be many other factors that require proper attention in determining the demand for electricity in the PRC. An important one, for example, is the weather. Cold days mean that more electricity will be used for heating and lighting. In winter, longer nights mean that lights are turned on much longer. Electricity demand also varies according to the time of day. Therefore, the demand for electricity also depends on weather changes: peak demands occur during cold weather and heat waves.[2] However, it is difficult to incorporate annual weather changes in assessing electricity demand.[3] On average, the weather factor is not expected to have a major impact on annual electricity consumption due to the small share of residential demand in the total electricity consumption in the PRC.

The increase in gas consumption and overall gas availability will provide increased competition for electricity in energy markets. However, direct competition is mainly limited to water heating with some competition in space heating and cooling markets. Because of the limited gas resources in the PRC, gas consumption will not have a significant impact on electricity consumption. Technological change and consumer preferences will affect electricity demand growth both negatively and positively and evolution of the competitive power market in the PRC could also affect electricity demand if competition could lead to lower electricity tariffs. Environmental policies could lead to higher supply cost and have a negative impact on electricity demand. However, all these factors are not expected to have a significant impact on electricity consumption at the current stage of economic development in the PRC.

[2] Weather-related variables, such as temperature, humidity, precipitation, and cloud cover are usually incorporated into the demand forecasting models used by utility companies. The ability to predict the weather can help the scheduling of generation. Also, in liberalized electricity markets, because of its impact on electricity demand, the weather can affect the price of electricity.

[3] If the forecasting were in days, weeks, months, or quarters, it would be important to have the weather factor.

Further, the growth rates of electricity demand also vary for different consumer categories and for different regions. For a particular province or power grid, electricity demand forecast could be made for the short term and the long term on a sector basis. However, to provide an aggregate electricity demand forecast for the PRC, it is difficult to gather sufficient data for a meaningful sector-base electricity demand forecast. Regional demand forecast is also limited by data availability. The focus of this paper is to develop a forecasting model that could be used for analyzing relationships between electricity consumption and macroeconomic variables and for providing key information for macroeconomic planning, such as total install capacity increase, investment requirement, and environmental impact. To achieve this, an aggregate approach using macroeconomic data at the national level is considered suitable.

A. Main Factors Determining Electricity Demand

The following five factors have been identified for their significant contribution to long-term electricity demand in the PRC.

1. Gross Domestic Product

GDP is considered to be the most important determinant for electricity consumption in the literature. Economic growth and its impact on living standards is the main driving force of electricity consumption growth. Empirical studies show that there should be a significant and stable positive correlation between GDP and electricity consumption.

2. Electricity Prices

As with income effects, electricity price is another important factor affecting electricity demand. However, electricity tariffs in the PRC have been set administratively according to the supply cost, including all fuel and operating and maintenance (O&M) costs, as well as recovery of construction costs and a reasonable profit. Setting electricity tariff in the PRC is a complicated and sensitive sector issue due to many authorized agencies involved in the approval process at different levels of government, and the presence of many stakeholders.[4] Despite this, electricity tariffs are an important variable in the electricity demand function because of its impact on electricity consumption.[5] Electricity tariffs in the PRC are set separately in each province and tariff adjustments require extended periods of evaluation and consensus making, further complicated

[4] Before 1985, electricity tariffs in the PRC remained at a relatively low level for many years, averaging about CNY0.07/kWh. Beginning in 1985, the tariffs were increased in response to increases in fuel prices and other capital and operating costs. Tariff proposals are prepared jointly by the provincial power companies and the provincial governments (mainly, the provincial price bureau) and submitted to the government, specifically the State Development and Planning Commission for approval.

[5] For example, the lower tariffs offered to big electricity consumers have reinforced the effect of investment–pull growth and contributed to the better than expected electricity consumption in 1999 and 2000.

by local add-ons at different levels even down to the small villages (estimated at 10 to 15 percent of the end-consumer tariffs). Tariff levels vary significantly from province to province and even within a province. Therefore, it is not possible to provide an estimated national average.[6] In this study, the fossil fuel price indexes[7] published by the National Statistics Bureau of China is used as the proxy of electricity prices because (i) they closely reflect the supply cost of generating electricity (70 to 75 percent of generation cost), (ii) thermal generation is the main source of electricity in the PRC (81 percent in 2001), and (iii) local add-ons relate to supply costs. It is expected that there exists a negative correlation between electricity demand and fuel price indexes.

3. Population Growth

Population growth is another important factor to determine electricity demand. Higher population growth is expected to increase electricity consumption. Population growth in the PRC has been kept at very low levels for two decades. However, because of its lager population base, population growth and improvement in living standards still have substantial impact on electricity consumption. In 2001, the population only grew at 0.69 percent, but the population increased by about 9 million. A positive correlation between population growth and electricity demand is expected.

4. Structural Changes in the Economy

Enterprise reforms have become an important aspect of macroeconomic policy in the PRC. Heavy industry has been the largest electricity consumer in the PRC. The growth of heavy industry has been the main contributor of electricity consumption growth, which usually uses up about 60 percent of the total electricity consumption. The correlation coefficient for the growth of electricity demand and the growth of electricity consumption of heavy industry was 0.9 between 1985 and 1997. Ongoing structural changes in the economy toward service- and export-oriented light industries, and state-owned enterprise (SOE) reforms that will lead to more closures of inefficient, large SOEs (particularly those heavy industries and large electricity consumers), have had a major impact on the electricity demand growth. For example, in the northeast region, despite a 9.2 percent GDP growth in 1998, electricity consumption only grew by 2.1 percent because of poor performance of large SOEs in the region. The smaller share of heavy industrial output implies lower growth in electricity demand. Thus, the variable (M2), which is the total industry share minus the share of the heavy industry in GDP, is included to reflect the industrial structure change occurring in the PRC. A negative relationship between GDP and the defined structural change is expected.

[6] Understanding how electricity tariffs have been set, and how the principles and priorities have been followed, is becoming important as competition in the electric power industry in the PRC expands.
[7] The government started to let the market determine coal prices since the early 1980s.

5. Efficiency Improvement

Annual per capita energy consumption in the PRC is relatively low at 0.66 tons (t) of oil equivalent (toe) in 2000, or about 40 percent of the world average. The energy intensity rate is still quite high, about 0.78 toe per $1,000 of GDP. Energy intensity declined during the 1990s, when GDP grew by 9.7 percent per year and energy consumption grew at 2.3 percent per year. As a result, the energy intensity index[8] dropped from 61.4 in 1990 to 30.3 in 2000. These indicate that energy conservation measures have produced significant positive results.[9] Therefore, efficiency improvement, that is, value-added produced by industry divided by electricity consumed by industry, is considered to be another important variable that determines electricity consumption. As new technologies and energy conservation measures are introduced in the industries, this ratio is expected to have a negative relationship with electricity demand.

B. The Model and Data

Based on the above discussion, a long-term electricity demand function for the PRC could be established as:

$$Q=f\ (GDP,\ P,\ POP,\ M2,\ EF) \qquad (1)$$

where Q is electricity demand, P is price, POP is population, $M2$ represents structural changes, and EF is efficiency.

The data for this study are taken from *China Statistical Yearbooks* (1985-2001), *China Electricity Yearbooks* (2000), and *Statistical Summary of Electricity Power Industry* (2001). Fuel prices are used as a proxy for electricity prices to incorporate the role of price elasticity. Fuel price indexes are projected based on their historical trends. Commodity Sales Index is used for price level. To investigate the difference of electricity demand in the previous planned economy and the current market-oriented economy, three periods are chosen to investigate Equation (1): 1952-2001 (whole period), 1952-1978 (before the reforms), and 1978-2001 (after the reforms). The GDP, population growth, and industrial growth projections are taken from the official Tenth Five-Year Plan (2001-2005) of the PRC.

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8 Expressed as unit of energy consumed per unit of GDP in 1978 constant prices, with the index set at 100 for 1978.

9 Some supply side measures such as the recent rural network rehabilitation and closure of small, inefficient generation units might have also contributed to this.

III. THE ECONOMETRIC ANALYSIS AND EMPIRICAL RESULTS

The existence of long-term equilibrium (stationary) relationship among economic variables is referred to in the literature as cointegration. The two common tests for cointegration are the procedure of Engle and Granger (1987) and the procedure of Johansen and Juselius (Johansen and Juselius 1990, Johansen 1995). The two-step procedure of Engle and Granger performs the tests in a univariate setup. Johansen and Juselius examine the question of cointegration and provide not only an estimation methodology but also explicit procedures for testing for the number of cointegration vectors as well as for restrictions suggested by economic theory in a multivariate setting. The Johansen technique is fast becoming an essential tool.

Following the procedure of Johansen and Juselius in defining a vector X_t of n potentially endogenous variables, it is possible to specify the following data generating process and model X_t as an unrestricted vector autoregressive (VAR) involving up to k-lags of X_t:

$$X_t = A_1 X_{t-1} +,\dots, A_k X_{t-k} + \varepsilon_t \quad \varepsilon_t \sim IN(O,\ \Omega) \tag{2}$$

where X_t is (n×1) and each of A_i is a (n×n) matrix of parameters. This type of VAR model has been advocated most notably by Sims (1980) as a way to estimate dynamic relationships among jointly endogenous variables without imposing strong priori restrictions (such as particular structural relationships and/or the exogeneity of some variables). The system is in the reduced form with each variable in X_t regressing on only lagged values of both itself and all the other variables in the system. Thus, Ordinary Least Squares (OLS) is an efficient way to estimate each equation since the right-hand side of each equation in the system comprises a common set of (lagged and thus predetermined) regressors. Equation (2) can be reformulated into a vector error correction model (VECM) form:

$$\Delta X_t = \Pi X_{t-k} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \varepsilon_t \tag{3}$$

where $\Gamma_i = -I + \sum_{j=1}^{i} A_j$ (for I=1,…k-1), and $\Pi = -I + \sum_{j=1}^{k} A_j$

The Granger representation theorem states that if the coefficient matrix Π has reduced rank $r<n$, then there exists $n \times r$ matrices α and β, each with rank r such that $\Pi = \alpha\beta'$ and $\beta' X_t$ is stationary. r is the number of cointegrating relations (the cointegrating rank) and each column of β is the cointegrating vector. The elements of α are known as the adjustment parameters in the vector error correct model. The Johansen method is to estimate the Π matrix in an unrestricted form, then test whether we can reject the restrictions implied by the reduced rank of Π.

Johansen and Juselius (1990) derive the cointegrating vector β by solving for the eigenvalues of

$$\left|\lambda S_{kk} - S_{k0} S_{00}^{-1} S_{0k}\right| = 0$$

where S_{00} is the moment matrix of the residuals from OLS regression of ΔX_t on $\Delta X_{t-1},...,\Delta X_{t-k+1}$, S_{kk} is the residual moment matrix from OLS regression of X_{t-k} on $\Delta X_{t-1},...,\Delta X_{t-k+1}$ and S_{ok} is the cross-product moment matrix. The cointegrating vector β is solved as the eigenvectors associated with the r largest statistically significant eigenvalues derived above (and ordered in descending order) using two test statistics, "maximum eigenvalue statistic" and "trace statistic." The first statistic tests the hypothesis that there exist r cointegrating vectors (against the alternative r+1) by calculating the maximum likelihood test statistic, LR_{max}, as below

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

where T is the sample size and λ_{r+1} is an estimated eigenvalue. The second statistic, the "trace statistics" (LR_{trace}) tests the hypothesis that there exist at most r cointegrating vectors by calculating the likelihood test statistic given by

$$LR_{trace} = -T \sum_{i=r+1}^{n} \ln(1 - \lambda_1) \quad r = 0,1,2,\ldots,n-1 \tag{5}$$

where T, as before, is the sample size and $\lambda_1,..., \lambda_n$ are the estimated n-r smallest eigenvalues. The distributions of these test statistics are as tabulated in Osterwald-Lenum (1992).

A. Unit Root Tests

The high growth rates of the PRC economy make time-series data unsteady and traditional OLS estimation might not satisfy the long-run models. To examine the time series properties of the data, we conduct the augmented Dickey-Fuller (ADF) and Phillips-Person (PP) unit root tests on the stationarity of the levels and the first differences of the variables in Table 1. In essence, for any variable z_t, testing the null hypothesis of $z_t \sim I(1)$ is equivalent to testing Δz_t being stationary. The ADF unit root test procedure is based on the OLS regression

$$\Delta z_t = \beta_0 + \alpha_0 T + \alpha_1 z_{t-1} + \sum_{i=1}^{m} \beta_i \Delta z_{t-1} + \varepsilon_t \tag{6}$$

where T is a liner time trend, and m is chosen to achieve white noise residuals, ε_t. Testing the null hypothesis of the presence of a unit root in z_t [the series is I(1)] is equivalent to testing the hypothesis that α_1=0 in Equation (6). If α_1 is significantly less than zero, the null hypothesis of a unit root is rejected. The results of two tests are reported in Table 3. As shown by the ADF and Phillips-Perron (PP) tests, we do not reject the null hypothesis that the level of each series is nonstationary. As a further check, we run the tests on all variables in their first differences. Both ADF and Phillips-Perron test results suggest that all variables are first-difference stationary, that is I(1). Consequently, they satisfy the necessary condition of constructing a cointegration system.

Table 3. **ADF and PP Unit Root Tests for Time Series Period, 1952-2001**

	Level		First Difference	
Series	ADF	PP	ADF	PP
LQ	–2.06	–2.93	–4.83**	–4.60**
LGDP	–2.50	–1.62	–5.30**	–4.59**
LP	–0.97	–0.25	–3.58**	–3.13**
LPOP	–1.51	–2.48	–6.62**	–11.20**
LM2	–2.57	–2.28	–5.48**	–5.83**
LEF	–1.84	–1.43	–4.50**	–3.84**

Notes: (1) L represents natural logarithm. For example, LQ=$ln(Q)$.
(2) * and ** indicate significance at 10 and 5 percent level respectively,

To assess further whether every explaining variable discussed above has a significant effect on dependent variable (electricity consumption) and coefficients estimated have the sign as we expected, we first use the OLS method to estimate the Equation (1) in natural logarithm:

$$LQ = \alpha + b\ LGDP + c\ LP + d\ LPOP - e\ LM2 - f\ LEF \qquad (7)$$

where Q is electricity demand, P is price, POP is population, $M2$ represents structural changes, and EF is efficiency variable. L represents natural logarithm as in Table 3. Using the macroeconomic data for regression, we obtain:

$$\begin{aligned} LQ = &-5.650 + 0.940LGDP - 0.032LP + 0.536LPOP - 0.560LM2 - 0.954LEF \\ &(0.719)^{*} \quad (0.035)^{*} \qquad (0.019)^{**} \quad (0.138)^{*} \qquad (0.021)^{*} \quad (0.025)^{*} \end{aligned} \qquad (8)$$

The sample range: 1952–2001, $\bar{R}^2$ = 0.999 DW=1.09, and F=25040.

Here, * (**) denote rejection of the hypothesis of the coefficient equal to zero at the 5 percent (10 percent) level. The number in parentheses are standard errors; the following parentheses are the same as in Equation (8).

Equation (8) shows that every regressing coefficient holds the sign expected although the low DW value of 1.09 displays existing correlation in residual. To analyze whether the results have triggered significant changes since the economic reforms, we further regress for the sub-sample, 1978-2001:

$$\underset{}{LQ} = \underset{(9.215)}{-4.169} + \underset{(0.253)^*}{0.797LGDP} - \underset{(0.037)^*}{0.121LP} + \underset{(1.655)}{0.506LPOP} - \underset{(0.080)^*}{0.313LM2} - \underset{(0.276)^*}{0.906LEF} \qquad (9)$$

Sample range: 1978 –2001, $\bar{R}^2$ = 0.999 DW=1.17, F=4638.

The results of Equation (9) show no significant changes. Thus, we use the whole sample period (1952-2001) in the following cointegration. As we mentioned above, it is difficult to make sure that the OLS regression Equation (8) would display the long-term relationship among the variables. Thus, the next stage naturally involves testing for the existence of cointegrating relationships (long-term equilibrium relationship).

B. Johansen Cointegration Test

In a multivariate system the Johansen-Juselius method of testing for cointegration between a set of variables is preferred over the Engle-Granger two-step procedure. We therefore use the Johansen-Juselius method trace test to determine the number of cointegrating vectors in our model. The Schwarz information criterion is used to determine the appropriate lag length of the VAR. The optimal lag order equals 2, which is determined by the information criterion. The results using the Johansen procedure are reported in Table 4.

Table 4. **Johansen Cointegration Test**

Hypothesized	Trace	5 percent	1 percent	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Critical Value
None **	0.688672	134.4600	102.14	111.01
At most 1 *	0.434973	79.61525	76.07	84.45
At most 2	0.380417	52.78379	53.12	60.16
At most 3	0.296002	30.28450	34.91	41.07
At most 4	0.170152	13.78842	19.96	24.60
At most 5	0.101347	5.022328	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5 percent(1 percent) level.
Trace test indicates 2 cointegrating equation(s) at the 5 percent level.
Trace test indicates 1 cointegrating equation(s) at the 1 percent level.

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5 percent Critical Value	1 percent Critical Value
None **	0.688672	54.84475	40.30	46.82
At most 1	0.434973	26.83146	34.40	39.79
At most 2	0.380417	22.49930	28.14	33.24
At most 3	0.296002	16.49608	22.00	26.81
At most 4	0.170152	8.766092	15.67	20.20
At most 5	0.101347	5.022328	9.24	12.97

*(**) denotes rejection of the hypothesis at the 5 percent(1 percent) level.
Max-eigenvalue test indicates 1 cointegrating equation(s) at both 5 percent and 1 percent levels.

Sample (adjusted): 1955-2001
Included observations: 47 after adjusting endpoints
Trend assumption: No deterministic trend (restricted constant)
Series: LQ, LGDP, LP, LPOP, LM2, LEF
Lags interval (in first differences): 1 to 2
Unrestricted Cointegration Rank Test

As reported in Table 4, both tests indicate that there exists a consistently cointegrating vector or long-run equilibrium relation among variables during the sample period of 1952-2001. The coefficient estimates of the cointegration vector are given by:

$$\beta' = (1.00, -0.856, 0.037, -0.338, 0.469, 0.187)$$

These values are normalized for *LQ, LGDP, LP, LPOP, LM2,* and *LEF*. They reflect long-run elasticity measures as the variables are in logarithms. The equation is presented as

$$LQ = 0.856LGDP - 0.037LP + 0.338LPOP - 0.469LM2 - 0.187LEF \quad (10)$$

Equation (10) indicates the long-term equilibrium relation among the variables for 1952-2001.

Similarly, we can estimate the long-term equilibrium relationship among these variables using the same cointegration for the sample range 1978-2001. The results are as follows:

Table 5. **Johansen Cointegration Test**

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	5 percent Critical Value	1 perzcent Critical Value
None **	0.975547	219.9782	94.15	103.18
At most 1**	0.724518	101.2262	68.52	76.07
At most 2 **	0.628049	59.97067	47.21	54.46
At most 3	0.461583	28.32285	29.68	35.65
At most 4	0.230707	8.510934	15.41	20.04
At most 5	0.003677	0.117882	3.76	6.65

*(**) denotes rejection of the hypothesis at the 5 percent(1 percent) level.
Trace test indicates 3 cointegrating equation(s) at both 5 percent and 1 percent levels.

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	5 percent Critical Value	1 percent Critical Value
None **	0.975547	118.7520	39.37	45.10
At most 1	0.724518	31.25551	33.46	38.77
At most 2	0.628049	26.64782	27.07	32.24
At most 3	0.461583	19.81192	20.97	25.52
At most 4	0.230707	8.393052	14.07	18.63
At most 5	0.003677	0.117882	3.76	6.65

*(**) denotes rejection of the hypothesis at the 5 percent(1 percent) level.
Max-eigenvalue test indicates 1 cointegrating equation(s) at the 5 percent level.

Sample: 1978-2001
Included observations: 24
Trend assumption: Linear deterministic trend
Series: LOG(Q) LOG(GDP) LOG(P) LOG(POP) LOG(M2) LOG(EF)
Lags interval (in first differences): 1 to 1
Unrestricted Cointegration Rank Test

As reported in Table 5, it turns out that two tests are consistent in existing one cointegrating vector or long-run equilibrium relation among variables during the sample range 1978-2001. The coefficient estimates of the cointegration vector are given by:

$$\beta' = (1.00, -0.7797, 0.0162, -0.5652, 0.5273, 0.3316)$$

These values are normalized for *LQ, LGDP, LP, LPOP, LM2*, and *LEF*. They reflect long-run elasticity measures as the variables are in logarithms. The equation is presented as

$$LQ = 0.780LGDP - 0.016LP + 0.565LPOP - 0.527LM2 - 0.332LEF \quad (11)$$

Equation (11) indicates the long-term equilibrium relation among the variables for 1978-2001.

The results indicate that there exists a stable long-run relationship among the variables in the model over the sample period. As expected, the relationship among variables is more stable and significant after the PRC's economic reforms (after 1978), when all factors became more responsive to market forces. Comparing Equation (11) with Equation (10), GDP elasticity is estimated at 0.78 for 1978-2001, lower than 0.86 of 1952–2001. This is consistent with efforts on energy conservation and more rapid structural changes in the economy in the postreform period. Further, both efficiency and structural change variables contribute more to electricity demand in the postreform years. Fuel price movements capture some price effects on electricity demand. As expected, the economic reforms also lead to more significant contribution to electricity demand from energy prices. Finally, population also plays a more important role in increasing electricity demand.

Since the structural change variable impacts significantly on electricity demand, it is possible to have significant diversions between GDP growth rates and electricity consumption growth rates during periods of rapid economic adjustments. Therefore, the diversions in 1997 and 1998 between GDP and electricity demand growth could be explained by the rapid structural changes in this period. The structural adjustments in the period could have been driven by SOE reforms, the Asian financial crisis, and slower economic growth in the PRC. Although slower demand also reflects improvement in electricity utilization efficiency as a result of adopting energy-saving technology and equipment, structural changes had a major impact on the lower electricity demand in this period. Among low-demand growth power networks, the traditional industrial base of the northeast region[10] experienced a 3.2 percent growth in 1997 and a –1.4 percent growth 1998 in electricity demand growth, while GDP growth rates were 9.3 percent in 1997 and 8.4 percent in 1998. The economic structure of the northeast region is dominated by heavy industry and SOEs.[11] Many large SOEs (mainly in heavy industry) in the region were closed and restructured during this period due to poor market conditions.

C. Long-run Electricity Demand Forecast

Using cointegration Equations (10) or (11), we can forecast aggregate electricity demand. The first problem of this procedure, however, is to project the trends of the variables in the right-hand side in Equations (10) or (11). GDP, population growth, and industrial sector growth are projected in the Tenth Five-Year Plan. As for data for other variables, we use time series techniques to predict them, in addition to official projections. Finally, electricity consumption is forecasted using the long-term Equations (10) or (11). The forecasting results are provided in Table 6.

[10] The northeast region includes Heilongjiang, Jilin, and Liaoning provinces. For example, because of the industrial structure and large urban population, Liaoning is the largest energy consumer in the PRC. Liaoning accounts for about 3 percent of the PRC's entire population but about 10 percent of total unemployment nationwide, leading to a growing concern of urban poverty.

[11] SOEs in Liaoning account for about one tenth of the total number of SOEs in the PRC.

Table 6. **Forecasting of Electricity Demand**

Year	Equation (10)	Equation (11)
2002	7.7	7.7
2003	6.7	6.7
2004	6.2	6.2
2005	5.9	5.9
Average (2002-2005)	6.6	6.7
2006	5.5	5.5
2007	5.1	5.1
2008	4.9	4.9
2009	4.8	4.8
2010	4.7	4.7
Average (2006-2010)	5.0	5.0
Average (2002-2010)	5.7	5.8

To have a closer look at the effects of structural changes, the electricity demand function was estimated in two periods. Though the scales of integration of independent variables are not the same, they satisfy cointegration criteria. The results conclude that there exists a stable long-term electricity demand function in the PRC. The elasticity of GDP is close to 0.8 and stable; structural changes, energy prices, and efficiency variables are all negative and less than 1. These results are consistent with expectations. GDP is the most important determinant of electricity demand. The estimated GDP elasticity with respect to electricity demand is very close to GDP elasticity with respect to energy demand, which was estimated to be 0.88.[12] This is expected as electricity represents the main form of energy consumption in the PRC. Using the results of Equation (11) in Table 6, the electricity demand growth rates are projected to be about 6.7 percent between 2002-2005, 5 percent between 2006-2010, and 5.8 percent between 2002-2010. As expected, Equation (10) and (11) produce very similar results.

The forecast of average 5.8 percent for 2002 to 2010 in Table 6 is lower than the historical trend of 9 percent in the period of 1978 to 2001, but close to the electricity demand forecast for the PRC provided by the US Department of Energy, which projected a 5.5 percent average annual growth in electricity consumption between 1990 and 2020, assuming an average GDP growth of 7.0 percent (see *International Energy Outlook* 2002). The forecast of 6.7 percent between 2002 and 2005 in Table 6 is higher than the 4.5 to 5 percent electricity demand growth planned in the Tenth Five-Year Plan assuming a 7.5 to 8 percent GDP growth. Based on the strong growth in electricity consumption in 2001 (9.2 percent) and 2002, the 4.5 to 5 percent growth forecast proves to be too conservative and the Tenth Five-Year Plan, which started with a power surplus, could end up with a power shortage. This view is supported by Wu (2002).

[12] Lin (2001) developed a long-run energy demand function for the PRC and estimated a 0.88 GDP elasticity.

IV. MAJOR EVENTS AFFECTING ELECTRICITY DEMAND IN THE SHORT TO MEDIUM TERM

There are some recent developments that could cause short-run fluctuations in the PRC's power demand.

A. Fiscal Stimulus

The reliance of electricity consumption on fiscal stimulus was evidenced by the close relationship between the growth of fixed investment, particularly in infrastructure development and the growth of the electricity consumption. The rapid growth in infrastructure investment led to an impressive increase in electricity consumption of large power consumers like steel and cement industries. Since 1997, the economic growth in the PRC was sustained by a series of fiscal stimulus measures.[13] One main driving force for the GDP growth was the growth of fixed asset investment for infrastructure development.[14] The impact of fiscal stimulus for infrastructure development was obvious as electricity demand quickly recovered from a 2.8 percent growth in 1998 to 6.1 percent in 1999, 9.4 percent in 2000 and 9.2 percent in 2001. The government's strategy of loose monetary policy and increased fiscal spending on infrastructure development is likely to sustain the 7 to 8 percent GDP growth and high power demand growth in the short to medium term, supported by persisting deflation.[15] However, there are apparent constraints to the sustainability of fiscal stimulus in the long run.

B. Tariff Incentives

Tariff incentives have been provided to encourage electricity consumption in many provinces with electricity supply surplus.[16] Power utilities in these provinces consistently campaign to exploit ways to increase power consumption since 1998. Up to now, tariff incentives have been the most effective way to encourage more consumption for some large electricity consumers. However, because of the complexity of the tariff issue, it is unlikely that tariff incentives could be used extensively. Tariff incentives could have substantial negative impact on the power utilities' balance sheets when the cost of supply goes up due to more new installed capacities that require full cost recovery. It is also debatable whether it is economically beneficial to encourage consumption by big electricity consumers without due consideration of environmental impact and efficient resource allocation. If such incentives are needed to attract or keep demand that would otherwise be lost, appropriately

[13] Government has committed itself to supporting the economy through funds raised via bond issuance.
[14] For example, it grew by 15.1 percent in 1999.
[15] While persisting deflation is symptomatic of structural problems associated with the massive oversupply of goods (about 70 percent of all commodities in 1999), it also reflects weak consumer confidence.
[16] Between 1998 and 2001, many major power networks in the PRC experienced surplus capacities reflective of the larger system reserve capacities and lower average generating hours.

designed discount rates are required to assure efficient electricity supply choices by customers and to avoid abusing tariff incentives. There were reports that provincial utilities offered large discounts on tariffs to big industrial consumers (usually heavy industry). Such measures included discounts on the state catalog tariffs and longer receivables.[17] It is difficult to estimate the impact of tariff incentives on electricity consumption as they were granted on a case-by-case basis at the local level. Though the tariff incentives could also be politically driven to save some SOEs, they mainly reflected the electricity surplus in these provinces. Therefore, tariff incentives are expected to have some impact only in the short run.

C. Residential Demand and Rural Electrification

The increase in residential consumption induced by the rapid increase in household appliances, particularly air conditioning units, is unlikely to bring up the national electricity growth average significantly, despite being a bright spot for about two decades with about 17.0 percent annual growth (nearly twice as fast as the national average), due to the limited overall weightings. Residential electricity consumption currently accounts for only 10 to 11 percent of the PRC's total electricity consumption. Further, many argue that the recent effort on rural electrification has provided a new opportunity for the growth of electricity consumption in the PRC.[18] However, this could be only a limited opportunity given the low overall weighting of agriculture and rural residential consumption (about 11.5 percent of the total). There is optimism that rural electrification will open up a large electricity market because of the enormous rural population in the PRC. First, rural electricity consumption is limited by low rural incomes. Second, rural electricity is inherently more expensive than urban electricity. The current pricing policy of "merging urban and rural grid system with a unified price" might result in urban residents paying more and therefore consuming less electricity in the coming years.

D. Power Sector Restructuring and a Competitive Power Market

The government has been actively restructuring the energy sector. The process has been, first, to improve governance by separating regulatory and operating responsibilities; second, to corporatize the operating entities; and third, to introduce market forces to improve efficiency and promote energy conservation. A 2002 Power Sector Restructuring Plan (PSRP)[19] recommends the

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[17] For example, Jiangxi Provincial Electricity Company offered a 20 percent discount on tariffs to two aluminum factories that consume 270 GWh annually (see *China Electricity Power News* 1999).

[18] The PRC plans to spend up to more than RMB 300 billion for urban electricity network upgrading and for developing and upgrading the rural electricity networks in the next three years (*China Electricity Power News* 1999). By May 1999, the PRC had invested RMB 22.3 billion for developing and upgrading rural electricity networks. Line losses in the rural areas were reduced from more than 25 percent to about 11.5 percent. Rural electricity tariffs were on average reduced by 0.1Yuan/kWh.

[19] The plan was announced at the press conference for the Fifth Session of the Ninth National People's Congress in March 2002.

dismantling of the existing SPC, and suggests that, except for 20 percent of the total generation capacity to be withheld by the grid companies as a peak-regulating tool, all other generation capacity must be restructured into five generation companies to ensure that the market share of each generation company would not exceed 20 percent in terms of generating capacity. In December 2002, a major step was taken by establishing five power generation companies to separate generation from transmission/distribution. Though it is difficult to predict how the power sector restructuring is going to impact on electricity demand, it is clear that electricity tariffs could not be brought down significantly to have a major impact on electricity demand in the short run. In the PRC, end-consumer tariffs could not be brought down without reforms in tariff setting. Tariff reform in the PRC is a very complicated issue and the end-consumer tariffs will continue to be under government control for a long time. Therefore, the current restructuring will have limited impact on the short- to medium-term electricity demand. However, electricity demand could be more responsive to tariffs as a competitive power market moves forward.

V. SHORT-TERM ELECTRICITY DEMAND FORECASTING: ERROR CORRECTION MODEL

The above major developments that could affect electricity demand growth in the PRC must be assessed for their effects on the long-term relationships expressed in Equations (10) and (11). There is need for testing if the long-term demand relationship established in the model will hold given the short-run disturbances. For this purpose, a dynamic error correction model, which can be used to forecast the short-run behavior of electricity demand, is estimated based on the cointegration relationship. For this purpose the lagged residual-error derived from the cointegrating vector is incorporated into a highly general error correction model. This leads to the specification of a general error correction model (ECM):

$$\Delta LQ = \beta_0 + \sum_{j=1}^{n}\beta_{1i}\Delta LQ_{t-j} + \sum_{j=1}^{n}\beta_{2i}\Delta LGDP_{t-j} + \sum_{j=1}^{n}\beta_{3i}\Delta LPOP_{t-j} + \sum_{j=1}^{n}\beta_{4i}\Delta LP_{t-j} + \sum_{j=1}^{n}\beta_{5i}\Delta LM2_{t-j} + \sum_{j=1}^{n}\beta_{6i}\Delta LEF_{t-j} + \beta_7\Delta EC_{t-i} + \varepsilon_t \qquad (12)$$

Once a cointegrating relationship is established, an ECM can be estimated subsequently to determine the short-run dynamic behavior of electricity demand. Following Hendry's (1995) general-to-specific modeling approach, we first include three lags of the explanatory variables and of the error correction (EC) term, and then gradually eliminate the insignificant variables. After experimenting with the general form of ECM (Equation 12), the following ECM is found to best fit the data (Table 7).

Table 7. **Estimated Error Correction Model**

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ΔLQ(-1)	0.088922	0.042342	2.100055	0.0434
EC(-1)	-0.434637	0.141429	-3.073186	0.0042
ΔLP(-1)	0.242332	0.113963	2.126409	0.0410
ΔLP(-2)	-0.221859	0.093752	-2.366441	0.0240
ΔLGDP	0.756169	0.056377	18.73414	0.0000
DLP(-3)	-0.183144	0.096390	-1.900030	0.0662
ΔLM2(-1)	-0.477649	0.036972	-12.91910	0.0000
ΔLEF(-1)	-0.831917	0.066095	-12.58663	0.0000
Adjusted R-squared		0.96		
Durbin-Watson stat		1.899		
Breusch-Godfrey Serial Correlation LM Test		F-statistic=0.54(0.58)		
Obs*R-squared=1.31(0.52)				
Jarque-Bera Normality		0.518		
White's Heteroscedasticity Test:		F=0.77		
ARCH		F=0.50		
RESET		F=1.81		

Dependent variable: ΔLQ
Method: Least squares
Sample (adjusted): 1955-1995
Included observations: 41 after adjusting endpoints

Several diagnostic tests performed are listed in Table 7. The diagnostic tests include Durbin-Watson (DW) test, Langrange-Multiplier test (LM) for serial correction, LM test for autoregressive conditional heteroskedasticity (ARCH), Jarque-Bera normality test, White's heteroscedasticity test, and Ramsey's reset test for functional form. According to the results of the diagnostic tests, they are insignificant for the error-correction model; the short-run model appears to be well behaved with a white noise error term. The plot of actual and fitted values (Figure 1) suggests that the short-run model tracks the data well. Further, the Cumulative Sum (CUSUM) test of parameter stability (Figure 2) indicates that the estimated parameters of the model have remained stable over the sample period, despite short-run disturbances.

In this model, GDP, energy price, and the structural changes have all emerged as significant determinants of short-term electricity consumption function for the PRC. The error correction coefficient, estimated at –0.434, is significant at the 1 percent level, has the correct sign, and suggests a high speed of convergence to equilibrium. This suggests that short-term fluctuations in electricity demand will not significantly affect the long-term relationship between electricity demand and the important variables, particularly GDP growth. This provides a relatively easy way of predicting electricity needs for the PRC.

Figure 1. **Plot of Actual and Fitted Values. Actual□LQ(—), Fitted(□)**

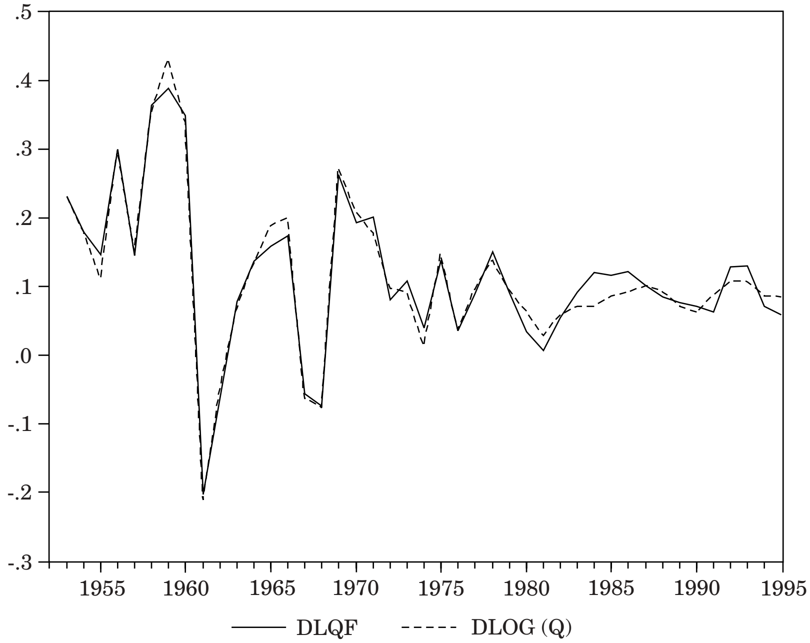
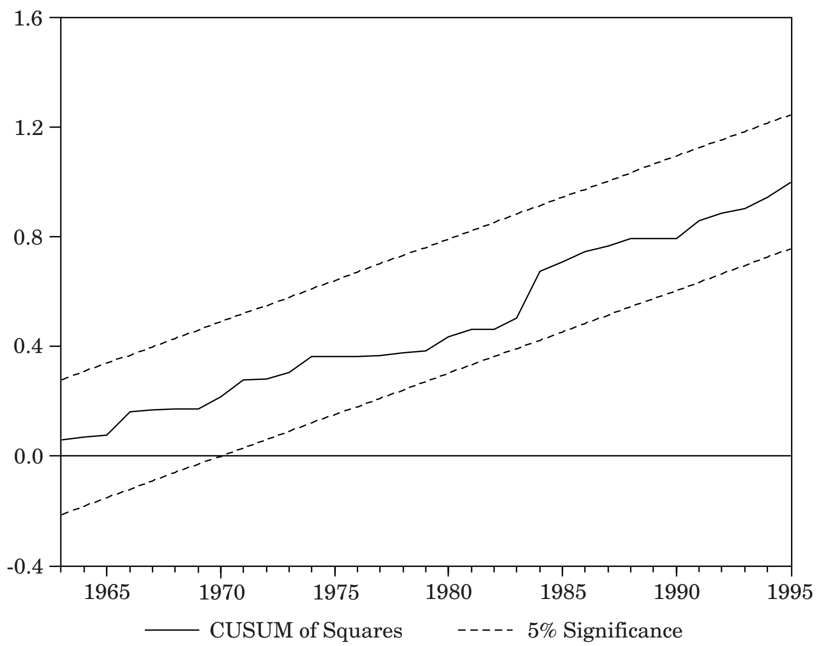


Figure 2. **Plot of Cumulative Sum of Recursive Residuals**



Note: The straight lines represent critical bounds at 5 percent significance.

To investigate the ex ante forecasting performance of the model, six additional observations covering 1996 to 2001 were added to the original sample period. The forecast results are presented in Table 8.

Table 8. **Forecast Revaluation**

Observations	Actual	Forecast
1996	7.4	6.9
1997	4.8	5.0
1998	2.8	-0.2
1999	6.1	6.3
2000	9.4	10.4
2001	9.2	8.9
Root Mean Squared Error		0.0211
Mean Absolute Error		0.019
Mean Absolute Percent Error		38.300
Theil Inequality Coefficient		0.1322

Notes: Suppose the forecast sample is $t = S, S+1,...,S+h$ and denote the actual and forecasted value in period t as y_t and $\hat{y}_t$ respectively. The reported forecast error statistics are computed as follows:

Root Mean Squared Error: $$\sqrt{\frac{1}{h+1}\sum_{t=S}^{S+h} (\hat{y}_t - y_t)^2}$$

Mean Absolute Error: $$\frac{1}{h+1}\sum_{t=S}^{S+h} \left|\hat{y}_t - y_t\right|$$

Mean Absolute Percentage Error: $$\frac{1}{h+1}\sum_{t=S}^{S+h} \left|\frac{\hat{y}_t - y_t}{y_t}\right|$$

Theil Inequality Coefficient: $$\frac{\sqrt{\frac{1}{h+1}\sum_{t=S}^{S+h}\left(\hat{y}_t - y_t\right)^2}}{\sqrt{\frac{1}{h+1}\sum_{t=S}^{S+h}\hat{y}_t} + \sqrt{\frac{1}{h+1}\sum_{t=S}^{S+h} y_t^2}}$$

The first two forecast error statistics depend on the scale of the dependent variable. These should be used as relative measures to compare forecasts for the same series across different models; the smaller the error, the better the forecasting ability of that model according to the criterion. The remaining two statistics are scale-invariant. Theil inequality coefficient always lies between zero and one, where zero indicates a perfect fit.

The model appears to track the data reasonably well, picking up all turning points in the data. The forecasting diagnostic tests reported in Table 8 confirm the accuracy of the model in predicting the short-run fluctuations in electricity demand; with the root mean squared errors of only 0.0211. Though the results in Table 8 indicate that some short-term fluctuations could reflect the impact of these factors discussed in Section IV, they do not have a significant impact on the long-term relationships established in Equations (10) or (11).

VI. INVESTMENT REQUIREMENTS AND ENVIRONMENTAL IMPACT

The forecast provided in Table 6 indicates that, though the power demand growth rates are expected to decline compared with the 9 percent average growth rates between 1978-2001, the increase is still substantial. Based on the forecast, electricity demand will have an increase of 63.3 percent for the period: from 1,446 terawatt-hours in 2001 to 2,362 terawatt-hours in 2010. To meet the demand, the PRC must address such important issues as how to meet the enormous capital requirements and how to prevent environmental deterioration. Equation (11) is used to calculate what those capital requirements may be, and to estimate potential environmental impact.

A. Investment Requirements

The PRC's high dependency on coal for electricity generation is expected to continue due to (i) the need to maintain low electricity tariffs, and (ii) abundant domestic coal supply. A major share of the increase in power supply during the period is expected to come from coal-fired power plants.[20] The nuclear power development could not meet the government's target of 4 percent in 2010 and is still at 1 percent of the total installed capacity. Although several large hydropower plants and a small number of diesel plants are under way, the share of hydro power plants will remain at about 24 percent and the share of diesel plants is negligible. For the purpose of estimating capital requirements and environmental impact, electricity generation is assumed to be 73 percent from coal-fired power; 25 percent from hydropower; and 2 percent from oil, natural gas, and nuclear power by 2010. The capital requirement for future power development was estimated on the basis of projections of installed capacity up to 2010.[21] First, the capital requirement for power plant construction by plant type was estimated. Then, the costs of construction of transmission and distribution were also estimated, using the assumed ratios of 40 percent transmission and distribution and 60 percent power plant construction costs. Based on these assumptions, the total

[20] The coastal regions, where growth in electricity demand is much higher than other regions, are far away from domestic coal mines. The PRC uses high-voltage lines to transmit electric power to the coastal regions from the southern provinces including Guangxi, Guizhou, and Yunnan.
[21] System losses, capacity factors, and load characteristics are based on the current levels and historical trends of major power grids.

installed capacity incremental is estimated to be 187 GW between 2002-2010[22] with 138 GW from coal-fired power plants, and the required investment costs are estimated to be US$193 billion in 2002 prices.[23]

A major concern in power sector development in the PRC is the enormous amount of investment that will be needed to meet the rapid demand growth for electricity. Raising such a large amount of capital will not be easy for the PRC and for the multilateral and bilateral financing institutions. So far, "build, operate, and transfer" and "build, operate, and own" (BOT/BOO) schemes have only played a very small role in the PRC's power development. Mobilizing domestic savings for the power sector will become an important measure because foreign capital will not be able to satisfy future investment requirements. In the PRC, domestic savings is about 38.5 percent of GDP, which could be mobilized through the domestic bond and stock market. Privatization of power plants could be another effective way of fund raising. Further, electricity tariffs in the PRC are distorted by the government to maintain low tariffs, particularly for certain categories of consumers. This weakens the financial position of a power utility in a competitive environment, which could in turn reduce its ability to mobilizing investment. Tariff reforms are necessary to support competitive power market development in the PRC and to strengthen the power utilities' financial position.

B. Environmental Impact

The rapid growth of power demand in the PRC and high dependency on coal for electricity generation will make the environmental impact of coal consumption of great concern. In the total incremental capacity of 187 GW between 2002-2010, 138 GW is expected from coal-fired power plants. The magnitude of the additional emissions from incremental coal-fired power plants could be estimated using the power industry's operational data and the current environmental standard set by the Government.[24] The PRC environmental laws and regulations require that newly constructed or expanded thermal power plants that emit sulfur dioxides (SO_2) exceeding the pollutant emission standards or total amount of control targets should install facilities for sulfur and dust removal or adopt other measures to meet the standards (Article 30, *Environmental Law*

[22] The No. 44 Document of the State Council issued in June 1999 provided a detailed schedule for the closure of thermal units 50 MW and below. Until 2003, the PRC will close 30,000 MW of small, inefficient thermal units. The closure, particularly of those units owned by local governments, has encountered difficulties. It is now clear that the closure could not be implemented according to the announced schedule. Though the closure will provide some space for the new additions in the short to medium term, it will not have significant impact on the required installed capacity given its small percentage against the total installed capacity and its long implementation period.

[23] Plant construction costs are estimated using current construction costs in the PRC. The capital cost of Yuan 4,800/kW for thermal power and Yuan 6,000/kW for hydropower were used in this study. The cost of transmission and distribution and other costs were estimated using the data provided by State Power Corporation of China and are estimated as percentages of the total investment in power development.

[24] Heat value of fossil fuels, sulfur and ash content, and thermal efficiency of power plants are taken from the average values of the power industry's operational data.

and Regulations in China 2002). In reality, electric precipitators and selective catalytic reduction processes are used for most new power plants. However, flue gas desulfurization is currently installed for only about 20 percent of new power plants. Most of those installed are located in more developed regions and some areas suffering heavily from SO_2. It is therefore assumed that 50 percent of newly constructed coal-fired power plants will be equipped with flue gas desulfurization in this period. The major environmental stressors including SO_2, nitrogen oxides (NO_x), particulate matter (PM_{10}), and carbon dioxides (CO_2) are estimated using the PRC power industry's operational data. It is estimated that 11.35 million tons of SO_2, 10.81 million tons of NO_x, 1.52 million tons of PM_{10}, and 2,398.78 million tons of CO_2 will be emitted from the incremental installation capacity to meet the forecasted power demand between 2003 and 2010. The government plans to control SO_2 emission at 18 million tons in 2005.[25] The incremental SO_2 emission will contribute a significant 6 percent of the total SO_2 emission planned for 2005 in the PRC. But the SO_2 emission from all power plants (including the incremental emission) will be 9.45 million tons and will contribute to about 53 percent of the planned total in 2005. The continuing growth of coal-fired power plants will increase the share of the power sector in the total SO_2 emission, from about 50 percent in 2001 to 53 percent by 2005, making the power sector the dominant air pollution source by 2010 (about 60 to 70 percent).

The PRC has severe environmental problems, primarily air and water pollution associated with rapid economic growth and the use of coal. Estimates of economic losses caused by pollution range from 3.5 to 8.3 percent of GDP.[26] The environmental impact from power development is a major source of the PRC's environmental problem and the emission share of the power sector will increase based on the projected demand growth.[27] Airborne concentrations of total suspended particulates (TSP), SO_2, and NO_x often substantially surpass environmental standards. The social cost of air pollution is high. Air quality is poor in most of the PRC's cities. Over 400 million people live in cities, and this number is expected to double by 2010. Annual premature (compared with life expectancy) deaths related to excessively high TSP concentrations are currently estimated at 150,000 in urban areas. Chronic pulmonary diseases linked to TSP exposure are a leading cause of death among urban residents, accounting for 9.1 deaths per 10,000 people, or about five times more than in the United States. The government should consider it a main environmental objective to reduce the growth of coal consumption for power development and the environmental pollution that such consumption causes. For this, the government should promote: (i) the introduction of clean coal technologies throughout the entire process of coal production, handling, transportation, and consumption; (ii) where possible, substitution of coal by natural gas, hydropower, and renewable energy; and (iii) demand-side management to decrease the growth rate in electricity consumption.

[25] The target was set in the Tenth Five-year Plan for environmental protection.

[26] Based on a study by the Policy Research Center for Environment and Economy of the State Environmental Protection Administration, pollution in the early 1990s caused annual economic losses of Y99 billion (about 4 percent of GDP), with air pollution accounting for 59 percent; water pollution, 36 percent; and solid waste, 5 percent.

[27] At present, about 75 percent of the power generation capacity in the PRC uses fossil fuels, and power generation is responsible for about 40 percent of air pollution.

VII. CONCLUSION

This paper was motivated by the need for an aggregate electricity demand forecast to facilitate estimation of capital requirement and environmental impact from power generation, and to fill the void in in-depth empirical analysis of determinants of electricity demand in the PRC, particularly nontraditionally defined variables such as structural changes and efficiency improvement. The paper develops an aggregate electricity demand model for the PRC. Based on the model, aggregate electricity demand is estimated to increase by an average of 6.7 percent annually between 2002 and 2005, and 5 percent between 2006 and 2010. The empirical results indicate that the electricity demand growth mainly reflects the changing expectations of GDP growth, population growth, structural changes, and efficiency improvement. The main conclusions of the paper are:

(i) There exists a stable long-run relationship among the variables in the model over the sample period. As expected, the relationship among variables is more stable and significant after the PRC's economic reforms (after 1978), when all factors were more responsive to market forces.

(ii) The demand elasticity of GDP is estimated at about 0.8 after the 1978 economic reforms, lower than that of the prereform period. Price and income (GDP) are important in the electricity demand function. The structural changes in the PRC economy have significant impact on electricity demand, particularly in the period of rapid economic adjustments. This implies that in a fast growing economy, high GDP growth does not always go hand in hand with high electricity demand, and in part explains why in 1998, when the PRC had an economic growth rate of 7.8 percent, electricity consumption grew by only 2.8 percent.

(iii) In the short run, the error correction model based on the long-term relationship established in Equations (10) or (11) appears to perform well and provides an appropriate framework for forecasting the short-run fluctuations in aggregate electricity demand. Some recent developments might cause short-run fluctuations in electricity demand, but have limited impact on long-term electricity demand.

(iv) The electricity demand growth rates are projected to be about 6.7 percent between 2002 and 2005, 5 percent between 2006 and 2010, and 5.8 percent between 2002 and 2010. Based on the strong growth in electricity consumption in 2001 and 2002, the 4.5 to 5 percent electricity growth set in the Tenth Five-Year Plan has proven to be too conservative and the Tenth Five-Year Plan, which started with a power surplus, could end with a power shortage.

(v) To meet the forecasted demand, the total install capacity incremental is estimated to be 187 GW between 2002 and 2010 and the investment costs are estimated to be US$193 billion in 2002 prices. The PRC must depend on domestic bond and stock markets and attract more foreign investments to meet capital requirements for projected power development projects.

(vi) For meeting the forecasted power demand between 2003 and 2010, it is estimated that the incremental installation capacity will emit 11.35 million tons of SO_2, 10.81 million tons of NO_x, 1.52 million tons of PM_{10} and 2,398.78 million tons of CO_2. Since power development will likely become a main source of air pollution, the government should promote clean coal technology and substitution of coal by natural gas, hydropower, and renewable energy.

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