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Working Papers in AGRICULTURAL ECONOMICS

March 1992

92-5

OIL SHOCKS AND THE DEMAND FOR ELECTRICITY

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Abstract

This paper uses a Structural Econometric Model - Time Series Analysis to forecast the demand for electricity in the US. The main innovation is to incorporate price shocks for oil into the model. The results show that if forecasts had been made with the model in the mid-seventies, they would have predicted the drop in growth of demand more quickly than the methods used by the electric utility industry. Using current data, forecasts of demand for 2000 from the model are higher than industry forecasts, suggesting a reversal of the situation that existed in the seventies.

1. INTRODUCTION

The construction of capacity to generate electricity requires substantial lead-time and considerable expenditure. Hence, the electric power industry has a recognized need for long-range forecasts of electricity demand. In the 25 years before the oil price shock of 1973-74, the demand for electricity in the U.S. grew steadily at about 8% compounded annually. Since that price shock, events have made electricity demand forecasting more uncertain, and typically, growth rates have been much lower. The objectives of this paper are 1) to show that the price of oil provides valuable information for forecasting the demand for electricity, and 2) that recent forecasts made by the utility industry may be too low.

A horizon of ten years is used in forecasting electricity demand (net energy for load) for capacity planning purposes by the National Electric Reliability Council (NERC). The NERC is composed of nine regional reliability councils that individually make projections of future demand on an annual basis. The NERC has published a summary of these projections starting in 1974, the year following the first oil price shock. In 1985, Nelson and Peck published a paper that evaluated the forecasting performance of NERC. Their primary interest was the fact that the aggregate NERC projections were consistently biased upwards throughout the 1970's, although the size of this bias decreased over time as new projections were made each year (Nelson and Peck refer to these projections as the "NERC fan").

The annual growth rates of the demand for electricity projected by the NERC are summarized in Figures 1a and 1b for five and ten years ahead. These figures show two series of 17 projections that were published annually from 1974 to 1991. For both series, the forecasted growth rates have declined over time from about 7% in the mid seventies to about 2% by 1985. For the past five years, the projected growth rates have remained roughly at that lower level. The last year of actual data available when the forecasts were made are shown on the horizontal axes of Figure 1. The actual average annual growth rates over the horizons 5 and 10 years ahead, corresponding to forecasts made using data through to 1985 and 1980, respectively, are also shown. Given the decline over time in the ten years ahead forecasted growth rates from their initial unrealistic levels, the forecast error has become much smaller. Similar comments can be made about the five years ahead forecasts. The main difference is that a comparison of the most recent five year forecasts and actual values show the forecasts to be consistently lower than the actual growth rates. In addition, actual five year growth rates follow a U shape over time, starting at about 3 percent , dropping to 1 percent in the late seventies and then increasing to 3 percent again by 1983.

Nelson and Peck used two analytical approaches to evaluate the NERC forecasts. Their objective was to determine whether the consistent upward bias of the forecasts in the 1970s was justifiable given information that was available at the time each forecast was made and given the forecasting methodology used at that time. Their two approaches were 1) A univariate ARIMA (0,1,1) model of the annual growth rate of sales, and 2) A single equation demand model using univariate exponential smoothing to project the exogenous variables (the price of electricity and real Gross National Product).

The results of Nelson and Peck's analysis are that the forecasts made by NERC (the forecasts from 1973 to 1982 in Figure 1) are very similar to Nelson and Peck's ARIMA forecasts and to the forecasts obtained by updating the demand model each year. The overall conclusion is that the performance of the NERC forecasts is reasonable based on this comparison with two conventional forecasting procedures. They conclude that "the 1970s were a period of instability and therefore one of learning for electricity forecasters---of learning about the uncertainties of energy costs and their impact on demand."

The underlying objective of this paper is to show that other useful information was indeed available in the 1970s, and by using this additional information, forecasters would have produced more accurate estimates of the future demand for electricity (see Chapman, Tyrrell, and Mount [1972]). The useful information comes from including the price of oil in the analysis. Since the start of the energy crisis in 1973 was initiated by an increase in the price of imported oil, this variable is clearly relevant to understanding changes in the demand for all forms of energy. All fossil fuel prices tended to increase after the oil embargo with the exception of natural gas prices which were relatively slow to increase because of regulation. This ubiquitous increase led to increasing costs for electricity generation, and eventually to higher prices for electricity also. At that time, the regulatory procedures governing electric power utilities' pricing were supplemented by fuel adjustment clauses so that price increases in fuel used for generation could be automatically passed on to customers.

The analysis that is described below uses a multivariate specification to capture the interdependencies between the price of oil and the demand for electricity. The model used is known as a Structural Econometric Model and Time Series Analysis (SEMTSA, see Zellner and Palm [1974] and Zellner [1979]). In this application, a system of equations is used to project the right-hand-side variables in an electricity demand equation. Specifically, price shocks for oil are used to project future prices of electricity and the Gross National Product. These in turn are the right hand side variables in the electricity demand equation. Forecasts made using data available in the mid 1970s are much more accurate than those made at that time by NERC. The results presented are also important from a current perspective. Since the price of oil dropped substantially in the mid 1980s and is still relatively low, the conclusion is that current NERC forecasts may underestimate the future demand for electricity. It should be noted that similar forecasts are produced by the Energy Information Administration and are subject to the same criticism. There are, however, some other possible explanations for these results that are discussed in the conclusions.

2. THE MODELING FRAMEWORK

A variation of the dynamic SEMTSA framework can be written as follows for a vector of M dependent variables (Y_t), K explanatory variables (X_t) q and N variables (Z_t) that are known functions of time period t:

$$\begin{bmatrix} A_0 + A(L) & -B_0 - B(L) \\ 0 & I_k + C(L) \end{bmatrix} \begin{bmatrix} Y_t \\ X_t \end{bmatrix} = \begin{bmatrix} G \\ H \end{bmatrix} [\ Z_t\ ] + \begin{bmatrix} U_t \\ V_t \end{bmatrix} \qquad (1)$$

where L is a lag operator ($L_i X_t = X_{t-i}$), $i = 0,1, ...$

$A_0 + A(L) = A_0 + A_1 L + A_2 L^2 + ...$

A_i is MxM for all i

$B_0 + B(L) = B_0 + B_1 L + B_2 L^2 + ...$

B_i is MxK for all i

$I_K + C(L) = I_K + C_1 L + C_2 L^2 + ...$

C_i is KxK for all i

G is MxN

H is KxN

U_t is an Mx1 vector of white noise residuals

V_t is a Kx1 vector of white noise residuals

(All elements of U_t and V_t may be correlated with each other)

I_K is a KxK identity matrix

A_0, A_i, B_0, B_i, C_i, G and H are matrices of unknown parameters, and

$t = 0,1, ..., T$ is the time period.

The form of the model in (1) implies that the elements of Y_t are determined simultaneously with the elements of X_t as explanatory variables. The matrix of zeros on the left hand side of (1), and the additional assumption that the residuals are uncorrelated through time, imply that Y_t does not Granger-cause X_t (see Newbold and Hotopp [1986]). The X_t are determined from a VAR model with functions of time (e.g. a trend variable) used to ensure stationarity (a similar model could specify a VAR for (X_t- X_{t-1})).

Two models closely related to those considered by Nelson and Peck can be specified as special cases of (1). The univariate ARIMA(0,2,1) model for the logarithm of sales of electricity (similar to an ARIMA (0,1,1) for growth rates) corresponds to the following specification:

$$(1 - L)^2 y_t = (1 + dL)(g + u_t). \qquad (2)$$

where, L and u are defined above, g is a constant, d is the parameter for a moving average process. y_t is 1x1 and represents the logarithm of sales of electricity, and u_t, g and d are all 1x1.

For the model in (2), the restrictions on (1) can be written (assuming the MA process is invertible, $|d| < 1$) as;

$$\begin{aligned} Y_t &= y_t \\ X_t &= 0 \\ U_t &= u_t \\ A_0 + A(L) &= (1 - L)^2/(1 + dL) \\ B_0 + B(L) &= 0 \\ G &= g \\ Z_t &= 1 \\ C(L) &= 0 \\ H &= 0 \\ V_t &= 0 \end{aligned}$$

The demand model proposed by Nelson and Peck is more directly related to (1). The two explanatory variables in X_t are real Gross National Product, x_{1t}, and the real price of electricity, x_{2t}. The model can be written:

$$\begin{bmatrix} 1 + aL & -b_{01}(1 + aL) & -b_{02} \\ 0 & (1 - L)^2/(1 + d_1 L) & 0 \\ 0 & 0 & (1 - L)^2/(1 + d_2 L) \end{bmatrix} \begin{bmatrix} y_1 \\ x_{1t} \\ x_{2t} \end{bmatrix} = \begin{bmatrix} g \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} u_t \\ v_{1t} \\ v_{2t} \end{bmatrix} \qquad (3)$$

where

$$Y_t = y_t$$

$$X_t' = [\, x_{1t}\ x_{2t} \,]$$

$$U_t = u_t$$

$$V_t' = [\, v_{1t}\ v_{2t} \,]$$

$$A_0 = 1$$

$$A(L) = aL$$

$$B_0 = [\, b_{01}\ b_{02} \,]$$

$$B(L) = [\, b_{01}a \quad 0 \,]\, L$$

$$I_K + C(L) = \begin{bmatrix} (1 - L)^2/(1 + d_1 L) & 0 \\ 0 & (1 - L)^2/(1 + d_2 L) \end{bmatrix}$$

$$G = g$$

$$H = 0$$

$$Z_t = 1_t.$$

The implication of (3) is that the sales of electricity are determined in a geometric lag model by the level of income and the price of electricity. These two explanatory variables are explained in turn by the two independent univariate ARIMA (0,2,1) models in Nelson and Peck's analysis.

The model used in this paper adds the price of oil as an additional variable to the system in (3). This makes it possible to capture the effects of OPEC policy. However, the most important change in the model is the recognition that the price of oil may affect all these variables. Rather than use univariate ARIMA models to forecast the input variables of the demand equation in (3), a dynamic multivariate model is used. Increases of the price of oil are expected to increase sales of electricity (oil is a substitute source of energy) and the price of electricity (by making fuels more expensive for generation) and decrease gross national product (by making an important factor of production more expensive).

Under the new specification, the three variables in (3) are treated as an interdependent system (y_{1t}, y_{2t} and y_{3t}), and the price of oil specified as a univariate ARIMA model with step functions to account for major swings in OPEC prices. The results show that the residuals in the equation for x_t are correlated with the residuals in other equations, and consequently the model does not exhibit a truly recursive structure even though x_t is not Granger-caused by any of the variables in Y_t.

3. DATA

Annual data covering the period from 1945 to 1990 inclusive was gathered from U.S. Government publications and from the Edison Electric Institute. The variables and their definitions are shown in Appendix Table A1 and the statistical characteristics of the data are shown in Appendix Tables A2 and A3.

The focus of this paper is on the demand for electricity. Figure 2 reports the level, first, and second differences of the logarithm of sales of electricity and it shows declining growth rates beginning in 1973. Earlier slow-downs appear to be associated with business cycle down-turns most notably those of November 1948 - October 1949, July 1953 - May 1954, and August 1957 - April 1958 (see Figure 2b). The shaded areas in Figure 2 correspond to the economic downturn dated by The National Bureau of Economic Research (see Moore and Zarnowitz [1986]). The plot of the first differences has a non-stationary mean. This non-stationary trend disappears after second differencing and is consistent with the ARIMA (0,2,1) model discussed above[1].

Time plots of the logarithms of other explanatory variables are shown in Figure 3. The shading corresponds to that in Figure 2. The long-run decline in the real price of electricity is notable as is the rapid run-up in the real price of fuel oil during or immediately proceeding the last four recessions.

4. ESTIMATION AND FORECASTING

The SEMTSA model was estimated[2] using two software packages, SAS (Version 5) (1984) and Time Series Processor (Version 4.2a) (1991) on two IBM 3090 installations, the Cornell National Super Computer Facility, and the SUNY Binghamton Computer. The first attempt was to estimate a model using a system of five equations for the logarithm of electricity sales (LKWH), Gross National Product (LGNP), and the prices of electricity, fuel oil for heating and natural gas (LPEL, LPFO, LPNG). The explanatory variables included current and lagged values of the dependent variables, dummies for various oil price shocks, and variables to proxy for technical change. Initial estimation was carried out treating the errors as autoregressive. The system was estimated via nonlinear three-stage least squares using appropriate twice lagged dependent variables, dummies, constant, and technological change proxies as instruments. Since the price of natural gas and the price of fuel oil were highly correlated [see Table A4] in the periods 1947-1980 and later, and the inclusion of the price of natural gas in the other equations made little difference in the fit[3], it was decided to drop the natural gas equation in the interest of parsimony.

To explore the inclusion of explanatory variables, the number of equations in the system, and the autoregressive structure, a number of tests were used. These included the standard error of the estimate of each equation, the log of the likelihood function of the system and the Akaike [1974] information criterion. The significance of individual coefficients was used to simplify the initial full model (in a manner consistent with Lovell [1983] and with Hendry, et al. [1984]). Likelihood ratio tests were also used in model construction. Residuals were plotted and tested via a non-parametric sign change test, and outliers were examined. A Ljung-Box [1978] Portmanteau test was also employed. Durbin-Watson, and when appropriate Durbin-h, statistics were also calculated to test for autocorrelated residuals. Finally, individual estimated coefficients were examined for plausibility. For example, if the coefficient for a lagged dependent variable was not statistically different from unity, using a Dickey-Fuller test, a difference equation would be substituted. In fact, the price of oil equation exhibited such a phenomenon.

Simulations were then run to the year 2000 from the prospective years of 1970, 1975, 1980, 1985, and 1990 (the latter under a variety of assumptions) using the estimate model for each time span. The results of the estimations of the models and the simulations are reported below.

5. ESTIMATION RESULTS

The equations (1) were estimated for five time spans, all originating in 1948 and ending in 1970, 1975, 1980, 1985, and 1990. While data exists back to 1945 for all variables, tests of the time series models for electricity demand starting in 1945 indicated that 1945 was from a substantially different regime[4]. Given the structure of an autoregressive model and the need for instruments that include twice lagged explanatory variables, the starting date of 1948 was chosen. Thus, data from 1946 and 1947 were required in this estimation.

The results of estimating each time span are shown in Table 1. The method used was to estimate the specification shown for the 1947-1990 period, and then to estimate this specification for earlier time spans, eliminating dummies as they became inoperative. In addition, the autoregressive term in the price of electricity equation was set to unity to aid in achieving convergence for the span 1948-1970.

It is useful to compare results across time spans. For electricity demand in all spans, the price of electricity (K3) enters negatively as expected, and the relationship is statistically significant in all but the first span (1948-1970). There is a substantial (67%) reduction in the size of the coefficient (-0.199 to -0.066) over the two time spans 1948-1975, and 1948-1990. There is no obvious explanation for this fall in the estimated price elasticity. Income (K2) enters the expression positively as expected. However, income is statistically significant only in the 1948-1990 span. The coefficient on lagged electricity sales (K1) is always about 0.9, and is always statistically significantly different from zero, and marginally significantly different from unity using a Dickey-Fuller test. Note that an autoregressive version of the demand for electricity equation was tested, but rejected it on the grounds that the estimated value of this parameter was small (about 0.135 to 0.155), and always statistically insignificant. Further, the inclusion of such a term was associated with a poorer Durbin-Watson statistic. This held for the system of 4 equations, but does not hold for a single electricity demand equation.

The GNP equation was specified to include lagged GNP, lagged and current oil prices (Y4 and Y5)[5], a time trend (YT), and a dummy that took the value of one from 1974 forward (DUMY

2). The equation was specified as an autoregressive one as this parameter proved significant. The coefficients in the GNP equation are relatively stable except for the price of oil whose influence wanes as the time spans are extended, but it is always negative. The trend coefficient is small as one would expect. The net effect of oil prices is negative in all time spans, and lagged GNP is still important even with a trend variable and an autoregressive structure.

Table 2 reports the statistics of the SEMTSA analysis for the five time spans. The most important finding is the notable consistency of the residual statistics across the spans. For example, the standard error of the electricity demand equation varies only in the third significant place over the five spans. The electricity price statistics for the 1948-1970 period are the only exceptions. The residuals from both price equations show some remaining serial correlation as evidenced by the Ljung-Box statistic, and, in the case of the electricity price, a substantially poorer fit as evidenced by the standard error. We conclude that the SEMTSA model is fairly stable over the five spans of our sample and produces reasonable parameter estimates.

6. EX-POST FORECASTING ACCURACY

Ex-post forecasts of the SEMTSA model and Nelson Peck's model of annual growth rates [ARIMA (0, 1, 1)] were made. Each model was used to generate a series of forecasts through 1990. The first year of each forecast was the first year following the estimation time span. These time spans bracket the oil price shocks of 1973-74, 1979-80, 1986, and 1990-91, and the possible regime changes of the Reagan Presidency (1981-1988). These forecasts of the demand for electricity were then compared to actual data and various summary statistics were calculated (see Tables A6, A7 and A8). The SEMTSA Model was superior to the N-P ARIMA in terms of the root mean squared error, the percent root mean squared error (PRMSE), the mean absolute deviation, and Theil's U-statistic. In general, the values for each statistic from the SEMTSA model are about two-thirds of those from the N-PARIMA. The comparison for PRMSE is shown in Figure 4.

7. EX-ANTE FORECASTS

Forecasts using the SEMTSA models estimated for different spans are summarized in Figures 5 to 8. The main conclusion for the sales of electricity (Figure 5) is that all SEMTSA models except the one estimated before the first oil shock (1948-1970) results in similar forecasts. The forecast from the 1948-1970 span implies lower oil prices (see Figure 8), lower electricity prices (see Figure 7), and higher GNP (see Figure 6) than the forecasts for the other spans. The overall effect is to increase the demand for electricity to roughly 9 trillion KWH by 2000. Although this value appears to be unrealistically high compared to the other four forecasts in Figure 5, it is interesting to note that a linear extrapolation of the first 10-year-ahead forecast made by NERC in Figure 1b (based on data to 1973) implies that sales would be over 10 trillion KWH by 2000.

The implied decrease in GNP associated with higher oil prices is significant. In 1990, forecasts of GNP range from 4.7 (1948-1970 span) to 4.1 (1948-1975 span) trillions of 1982 dollars, a difference of 15%. The corresponding high and low forecasts for 2000 are 6.4 (1948-1970 span) and 5.5 (1948-1975 span) trillions of 1982 dollars, respectively, a difference of 16%. The forecast using the complete set of data (1948-1990 span) is 5.9 trillions of 1982 dollars in 2000. Jorgenson and Wilcoxen (1990) compared the long-run solutions for real GNP using low oil prices (i.e. 1972) versus high oil prices (i.e. 1981) and found a difference of only 2.5%. Hence, the SEMTSA results suggest that GNP is more responsive to oil prices. Comparing the forecasts for 2000 using the 1948-1970 span and the 1948-1980 span (a more direct comparison to Jorgenson and Wilcoxen's results) gives a difference of 9.2% in real GNP.

Given the importance of the price of oil in determining levels of the other three variables in the model, a second series of ex-ante forecasts was made for the period 1991-2000 using the model estimated for the 1948-1990 span. The forecasts were derived using different projections of future oil prices corresponding to three scenarios reported by the EIA in the 1991 *Annual Energy Outlook*. These projections hold the real price of oil constant from 1991 to 1995, followed by exponential growth. The initial levels from 1991 to 1995 and final growth rates vary by scenario.

The resulting forecasted growth rates of sales of electricity and real GNP are summarized in Table 3 together with the corresponding forecasts from the complete SEMTSA model. In all cases, the forecasted growth rates for sales of electricity are higher than the most recent NERC forecast shown in Figure 1. The conclusion is that the current NERC forecast is consistent with a substantial increase in the price of oil, a recession caused by factors that are not reflected in the SEMTSA model, or a decrease of demand due to non-market forces. The latter effect could be attributed to current efforts by utility planners to encourage demand-side-management. However, an equally important possibility that would have the opposite effect on demand would be policies encouraging the use of electric vehicles to improve urban air quality.

8. CONCLUSION

In view of the above estimation and forecast results, the conclusion reached by Nelson and Peck is too forgiving. If utility forecasters in the 1970s had recognized that valuable information was contained in the price of oil, their forecasts would have been substantially better. Nelson and Peck correctly conclude that the 1970s were a time of learning for forecasters, but like generals who are reputed to use tactics appropriate for the last war, the utility forecasters continued to rely on methods that had worked prior to the first oil shock, and neglected new information. Using all available data through 1990 in a SEMTSA model suggests that current NERC demand forecasts are too low.

The NERC forecasts assume implicitly that one or more of the following situations will occur: 1) the price of oil will be higher than the levels forecasted by the EIA, 2) the price of electricity will be higher due, for example, to additional costs for environmental controls, 3) the current economic recession will continue, and 4) that non-market reductions of demand will occur due to energy conservation. One thing is clear, however. The current recession can not be blamed on the price of oil.

ENDNOTES

1. The possibility of modeling the sales of electricity by an ARIMA (p, 2 q) was explored. Unfortunately, the data are too short to support a reasonable time series estimation with second differencing. For example, an estimation of an ARIMA (1,2,3), trend (the inverse of the square root of time) for data covering 1947-1988 yielded the following unstable results.

Parameter	Estimate	t-ratio
MA1	-0.271	0.01
MA2	0.786	0.04
MA3	0.058	0.04
AR1	0.993	107.59
Trend	-0.402	1.53

2. We also estimated a number of other models using our data and the results are available upon request. The first of these was a model analogous to the first Nelson and Peck model (see equations (2) and (3)). The first was a first order moving average model of the change in growth rate, g.

$$g_t - g_{t-1} = \varepsilon_t + \theta\varepsilon_{t-1}. \qquad (2.1)$$

The second NP model is based on the Houthakker-Taylor [1970] (HT) stock adjustment model using lagged prices and income as independent variables. The original HT model was:

$$KWH_t = B_o + B_1\, KWH_{t-1} + B_2\, Y_t + B_3\, PEL_t + V_t \qquad (2.2)$$

where Y and PE denote income and electricity price respectively. We estimate a per capita model based upon this HT model, but did not pursue it for forecasting.

Garcia-Ferrer et al., [1987] employed two naive models (NM), as suggested by Milton Friedman to forecast macro economic variables. The models are:

$$\text{NM1:} \quad g_t = 0 \tag{2.3}$$

$$\text{NM2:} \quad g_t = g_{t-1} \tag{2.4}$$

The NM1 model forecast will be optimal in the percent root mean squared error (PRMSE) sense if the logarithm of sales follows a random walk. The NM2 model forecast is PRMSE optimal if g_t follows a random walk.

Finally, a number of univariate and intervention time series models were estimated, but these proved unstable over varying time spans.

In all cases, none of these methods were able to generate better forecasts than did the SEMSTA model. Our version of the NP model mimicked NP's results and only gradually recognized the impact of prices. The per capita version of the HT model required further forecasts of exogenous variables to properly forecast electricity demand. The NM1 model constantly misses the mark for long-run forecasts as sales do indeed change. The NM2 model simply claims that what ever caused a historic growth rate will prevail in the future and also thus misses the mark.

3. The standard errors for each equation of the final specification (estimated over data from 1947 through 1988) are given for models including a simultaneous natural gas equation and excluding a simultaneous natural gas equation as:

	Including	Excluding
LKWH	.0236	.0228
LGNP	.0223	.0225
LPEL	.0267	.0272
LPOH	.0523	.0519

4. The arguments for the inclusion of data from 1945 are that it was not a "war year" (war production peaked in 1943 and the conduct of the war was winding down in the first half of 1945), and the general argument that all data should be cherished. The arguments for its exclusion are that is was a transition from war to peace year, plots show it to be a serious outlier (logarithms, and first and second differences) and there is reason to suspect a high degree of measurement error. It is possible that this exclusion/inclusion issue is one of model fragility. Hence, we tested the issue via a number of ARIMA models. In general, an ARIMA (1, 1, 1) could not discern between exclusion/inclusion whereas an ARIMA (0, 2, 1) supported the exclusion of 1945. The excluded estimate lead to a lower standard error (adjusted for the number of observations), a lower coefficient of variation on forecast errors, and avoided a unit root problem on the MA term.

5. Current oil prices were eliminated from the GNP equation for the 1948-1970 span because of collinearity problems.

REFERENCES

Akaike, H., A New Look at the Statistical Model Identification, *IEEE Transactions on Automatic Control*, 1974, AC-19, pp. 716-723.

Box, G.E.P. and D.A. Pierce, Distribution of the Residual Autocorrelations in Auto-Regressive-Integrated Moving-Average Time Series Models, *Journal of the American Statistical Association*, 65, December, 1970, pp. 1509-1956.

Chapman, L.D., T.J. Tyrrell and T. D. Mount, Electricity Demand Growth and the Energy Crisis, *Science*, 1972, 178, pp. 703-708.

Council of Economic Advisers, "Economic Report of the President," (Washington: U.S. Government Printing Office), January 1989.

Dickey, D. A. and W. A. Fuller, Distribution of the Estimators for Autoregressive Time Series with a Unit Root, *Journal of the American Statistical Association,* 1979, 74, pp. 427-31.

Edison Electric Institute, Statistical Yearbook of the Electric Utility Industry, 1987, December 1988 (Washington: Edison Electric Institute) 1987 (and earlier editions).

Garcia-Ferrer, A., R. A. Highfield, F. Palm, and A. Zellner, Macroeconomic Forecasting Using Pooled International Data, *Journal of Business and Economic Statistics,* January 1987, 3, 1, pp. 53-67.

Hendry, D.F., A.R. Pagan and J. D. Sargon, Dynamic Specification, in Griliches, Zvi and M.D. Intriligator, Handbook of Econometrics, 1984, 2, pp. 1023-1100.

Houthakker, H. S., and L.D. Taylor, *Consumer Demand in the United States, 2nd Edition*, (Cambridge, MA: Harvard University Press), 1970.

Jorgenson, D. W. and P. J. Wilcoxen, *Global Change, Energy Prices, and U.S. Economic Growth*, Discussion Paper No. 1511, 1990.

Ljung, G. M. and G. E. P. Box, On a Measure or Lack of Fit in Time Series Models, *Biometrica*, 1978, 65, pp. 297-303.

Lovell, M. C., Data Mining, *The Review of Economics and Statistics*, 65, 1, February 1983, pp. 1-12.

Moore, G. H., and V. Zarnowitz, The Development and Role of the National Bureau of Economic Research's Business Cycle Chronologies, in Gordon, Robert J. editor, *The American Business Cycle*, (Chicago: The University of Chicago Press) 1986.

Nelson, C. R., and S.C. Peck, The Nerc Fan: A Retrospective Analysis of the NERC Summary Forecasts, *Journal of Business and Economic Statistics*, July 1985, 3, 3, pp. 179-187.

Newbold P. and S. M. Hotopp, Testing Causality Using Efficiently Parameterized Vector ARMA Models, *Applied Mathematical Comput.*, 1986.

SAS Institute, *SAS/ETS User's Guide, Version 5*, (Cary, N.C.: SAS Institute Inc.) 1984.

TSP International, TSP Reference Manual, Version 4.1, (Stanford, CA), 1988.

U.S. Department of Commerce, Bureau of Economic Analysis, *Survey of Current Business*, various issues, (Washington: U.S. Government Printing Office).

U.S. Department of Labor, Bureau of Labor Statistics, *CPI Detailed Reports*, various dates.

U.S. Department of Labor, Bureau of Labor Statistics, *Handbook of Labor Statistics*, various dates.

Zellner, A., Statistical Analysis of Econometric Models, *Journal of The American Statistical Association*, 1979, 74, pp. 628-643.

Zellner, A. and F. Palm, Time Series Analysis and Simultaneous Equation Econometric Models, *Journal of Econometrics*, 1974, 2, pp. 17-54.

Table 1

Estimated Parameters and Standard Errors for the Structural Econometric and Time Series Analysis of Electricity Demand

Parameter	Symbol	Using Data From 1948 to the Year Ending 1970	1975	1980	1985	1990
KWH Equation						
Intercept	KO	1.565	1.527	0.768	0.654	0.646
		(1.033)	(0.541)	(0.210)	(0.122)	(0.094)
KWH (t-1)	K1	0.907	0.860	0.877	0.937	0.904
		(0.039)	(0.044)	(0.043)	(0.035)	(0.027)
GNP (t)	K2	0.006	0.101	0.151	0.049	0.110
		(0.082)	(0.098)	(0.087)	(0.067)	(0.049)
PEL (t)	K3	-0.172	-0.199	-0.103	-0.062	-0.066
		(0.131)	(0.072)	(0.035)	(0.026)	(0.024)
GNP Equation						
Intercept	Y0	5.969	5.166	5.230	4.293	3.931
		(1.456)	(1.938)	(2.485)	(2.060)	(2.463)
GNP (t-1)	Y2	0.481	0.512	0.328	0.455	0.493
		(0.151)	(0.263)	(0.333)	(0.275)	(0.337)
PFO (t)	Y5	-	-0.180	-0.017	-0.070	-0.056
		-	(0.138)	(0.050)	(0.036)	(0.032)
PFO (t-1)	Y4	-0.201	-0.125	-0.082	-0.018	-0.012
		(0.077)	(0.056)	(0.047)	(0.034)	(0.030)
Time (t)	YT	0.013	0.014	0.023	0.018	0.015
		(0.005)	(0.009)	(0.011)	(0.009)	(0.010)
Dummy (1974 →)	DUMY2	-	0.060	-0.001	0.037	0.035
		-	(0.060)	(0.028)	(0.021)	(0.022)
Auto Regressive	RHOY	0.421	0.363	0.552	0.477	0.524
		(0.120)	(0.208)	(0.303)	(0.274)	(0.327)
Electricity						
Intercept	PEO	-112.056	-2.065	-0.234	-0.841	-0.332
		(77.501)	(1.272)	(0.706)	(0.463)	(0.319)
GNP (t-1)	PE2	0.219	0.023	-0.094	0.060	-0.026
		(0.104)	(0.145)	(0.107)	(0.065)	(0.041)
PFO (t)	PE5	-2.741	0.283	0.201	0.171	0.160
		(0.072)	(0.057)	(0.050)	(0.035)	(0.032)
PFO (t-1)	PE4	1.436	0.104	0.034	-0.091	-0.023
		(0.399)	(0.077)	(0.068)	(0.044)	(0.038)
PEL (t-1)	PE3	0.383	0.398	0.661	0.852	0.765
		(0.105)	(0.175)	(0.146)	(0.076)	(0.054)
$Time^{-1}$ (t)	ET	0.159	2.789	0.558	0.659	0.478
		(0.335)	(1.247)	(0.402)	(0.349)	(0.269)
Auto Regressive	RHOE	-	0.725	0.416	0.431	0.382
		-	(0.061)	(0.184)	(0.099)	(0.108)
Oil Price Equation						
Intercept	P00	-0.005	-0.003	-0.002	-0.012	-0.011
		(0.009)	(0.009)	(0.008)	(0.009)	(0.009)
PFO (t-1)	P04	0.463	0.100	0.098	0.256	0.198
		(0.135)	(0.094)	(0.082)	(0.077)	(0.073)
Dummy (1974 →)	DUMO2	-	0.403	0.430	0.449	0.492
		-	(0.045)	(0.044)	(0.057)	(0.065)
Dummy (1979 →)	DUMO3	-	-	0.471	0.488	0.468
		-	-	(0.064)	(0.085)	(0.092)
Dummy (1986 →)	DUMO4	-	-	-	-	-0.169
		-	-	-	-	(0.068)
Dummy (1990 →)	DUMO5	-	-	-	-	0.174
		-	-	-	-	(0.045)

Table 2
System Statistics

Statistic	Using Data 1948 Through the Year Ending 1970	1975	1980	1985	1990
No. of Obs.	23	28	33	38	43
Complete System					
Log of Likelihood	- 743.01	- 876.93	-1016.57	-1171.25	-1317.54
AIC	1520.01	1711.86	1989.15	2298.50	2683.08
AIC/N	66.09	61.14	60.28	60.49	62.40
KWH					
Std Error	0.0262	0.0229	0.0227	0.0251	0.0227
Adj. R-Sq.	0.998	0.999	0.999	0.999	0.999
Durbin h	-0.369	-0.588	-0.539	-0.365	-0.415
% Sign Change	52.2	64.3	54.5	55.3	51.2
Ljung Box, L = 5[b]	2.55	2.19	0.57	5.04	8.08
Ljung Box, L = 10	9.58	11.20	11.80	10.10	13.6
GNP					
Std. Error	0.0220	0.0127	0.0204	0.0233	0.0229
Adj. R-Sq.	0.992	0.994	0.996	0.996	0.997
Durbin h	-0.896	2.350[a]	2.07[a]	2.21[a]	2.26[a]
% Sign Change	65.2	57.1	51.5	50.0	53.5
Ljung Box, L = 5	1.65	1.42	3.32	0.97	2.54
Ljung Box, L = 10	7.11	8.30	9.43	6.40	7.33
PEL					
Std Error	0.1123	0.0260	0.0265	0.0291	0.0262
Adj. R-Sq.	0.781	0.988	0.986	0.981	0.982
Durbin h	-2.275	-2.519	-2.364	-1.475	-1.311
% Sign Change	78.3	57.1	54.5	60.5	55.8
Ljung Box, L = 5	11.4	3.85	4.93	2.73	2.97
Ljung Box, L = 10	17.6	6.30	8.13	6.78	5.91
PFO					
Std Error	0.0420	0.0440	0.0433	0.0518	0.0523
Adj. R-Sq.	0.646	0.850	0.959	0.977	0.974
Durbin h	-2.769	-0.444	-0.748	-1.167	-1.128
% Sign Change	69.6	67.9	57.6	65.8	67.4
Ljung Box, L = 5	10.20	3.61	6.65	3.43	3.35
Ljung Box, L = 10	15.80	12.80	14.50	8.22	9.00

a Durbin Watson reported; h irrational.

b Ljung Box, L = 5 is the Ljung Box Statistic at 5 lags, and similarly 10 lags for L = 10. Both are distributed ^{2} with $^2_{5df, \alpha = 5\%} = 11.07$ and $^2_{10df, \alpha = 5\%} = 18.31$.

An h calc. $\geq |1.96|$ implies rejection of the null hypothesis that there is no first order serial correlation.

Table 3
Forecasted Growth Rates for
Electricity Sales and GNP

	Average Annual Growth Rates 5 Years Ahead 1990-1995	Average Annual Growth Rates 10 Years Ahead 1990-2000
Electricity Sales		
Scenario*		
1. SEMTSA	3.81	4.12
2. Low Poil	5.17	4.42
3. Base Poil	3.57	3.67
4. High Poil	3.02	3.09
GNP		
Scenario*		
1. SEMTSA	3.34	3.36
2. Low Poil	3.70	3.39
3. Base Poil	3.08	3.00
4. High Poil	2.58	2.35

*All scenarios use the SEMTSA model estimated from the 1948-90 span. Scenario 1 corresponds to the forecasts presented in Figures 5 and 6. Scenarios 2-4 correspond to three different assumptions about future oil prices based on EIA scenarios.

Table 4

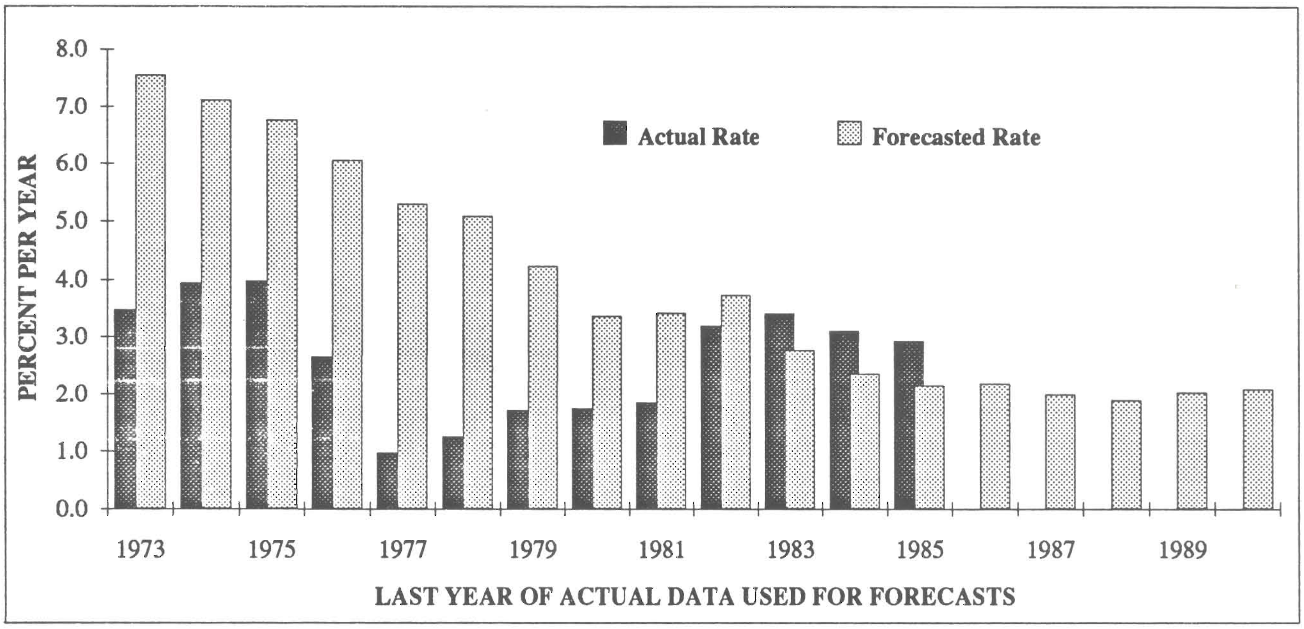
Electricity Sales

1990 Actual and Forecasts for 2000

Actual/Forecast	Pecta Watt Hours
Actual 1990	2.67
Forecast 2000	
SEMTSA Model	4.08
SEMTSA Using EIA Oil Price Scenarios	
Low Price Oil	4.19
Base Price Oil	3.90
High Price Oil	3.69
EIA Reference	3.25
NERC Projection	3.25

FIGURE 1
SALES OF ELECTRICITY IN THE U.S.
NERC FORECASTS OF ANNUAL GROWTH RATES AND ACTUAL EXPERIENCE

a) FIVE YEARS AHEAD



b) TEN YEARS AHEAD

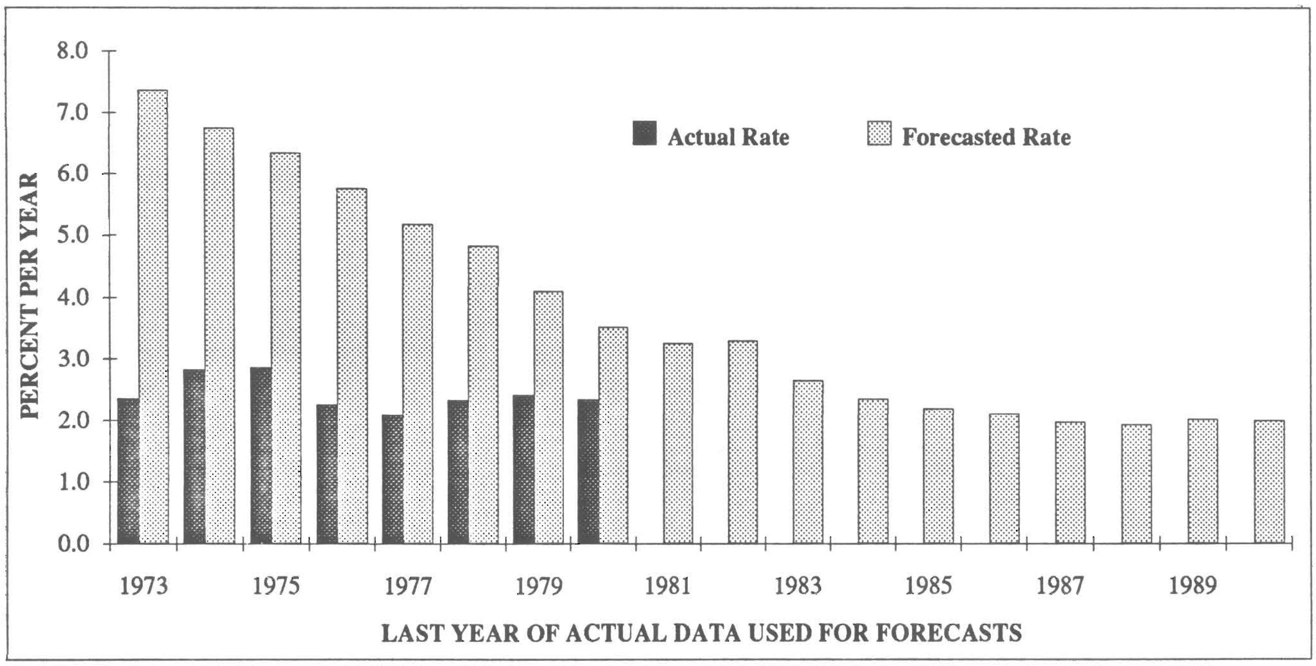


FIGURE 2
SALES OF ELECTRICITY IN THE U.S. (1947-90)

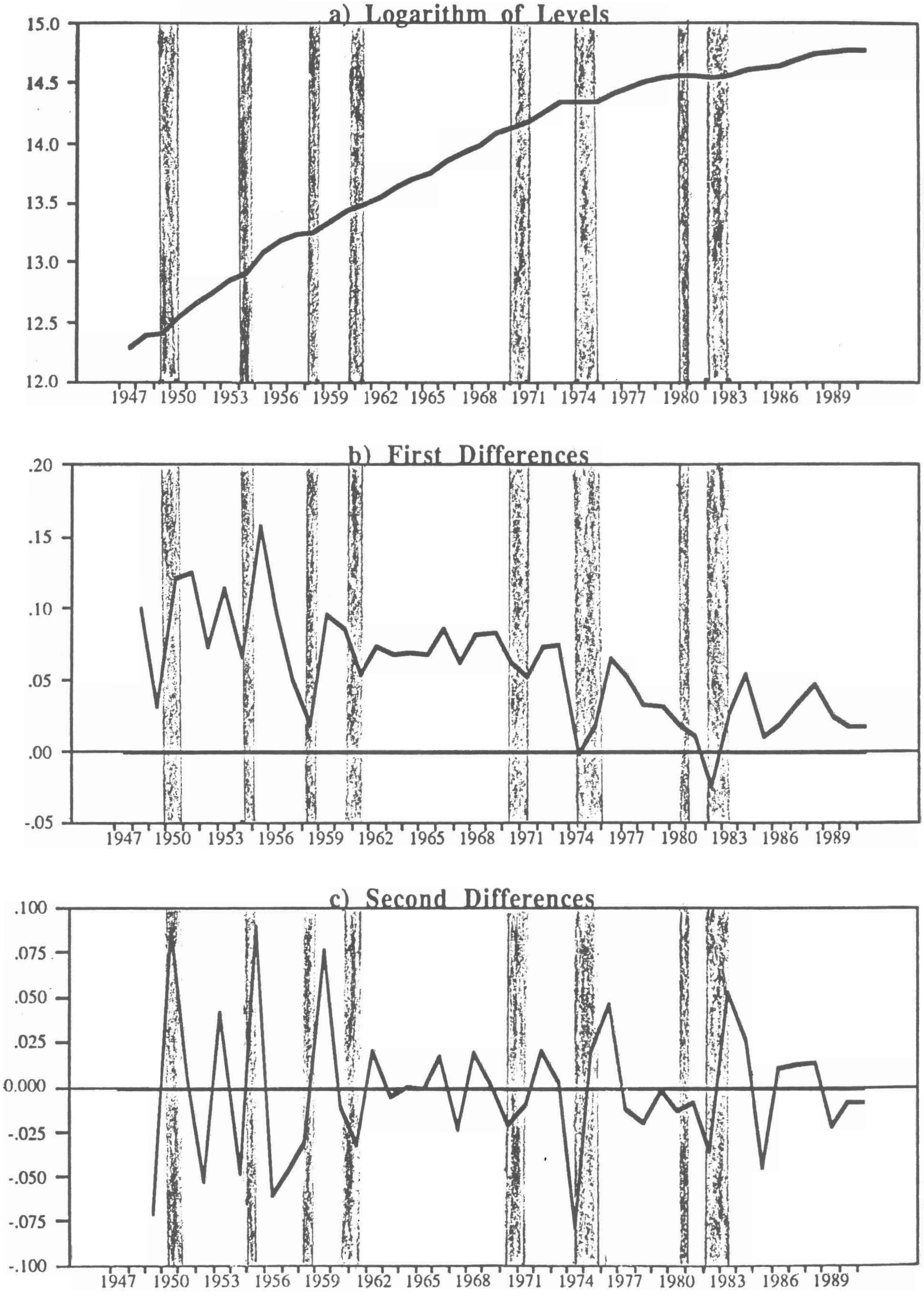


FIGURE 3
OTHER EXPLANATORY VARIABLES (1947-90)

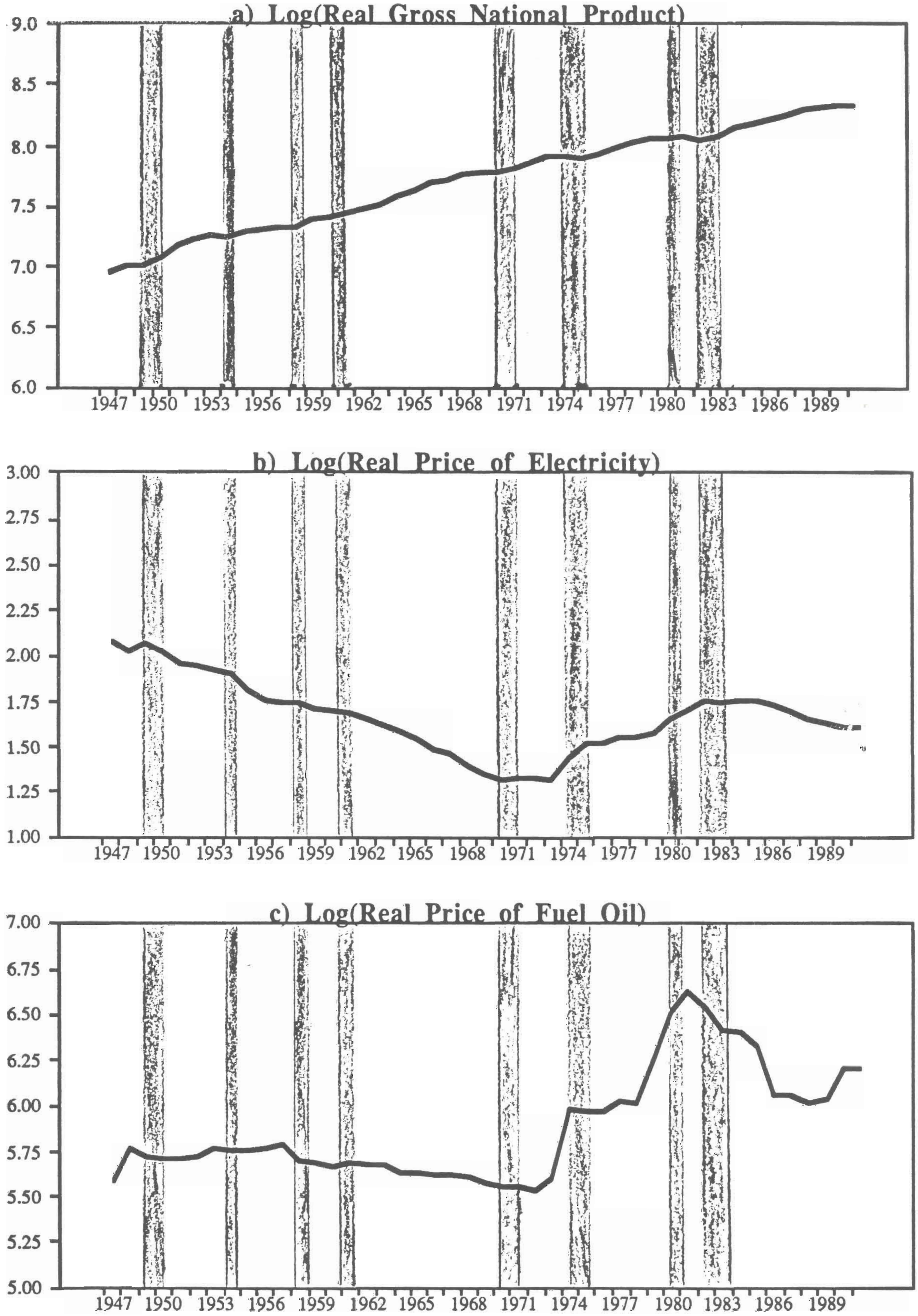


FIGURE 4
ACCURACY OF EX-POST FORECASTS TO 1990
(PERCENTAGE ROOT MEAN SQUARED ERROR)

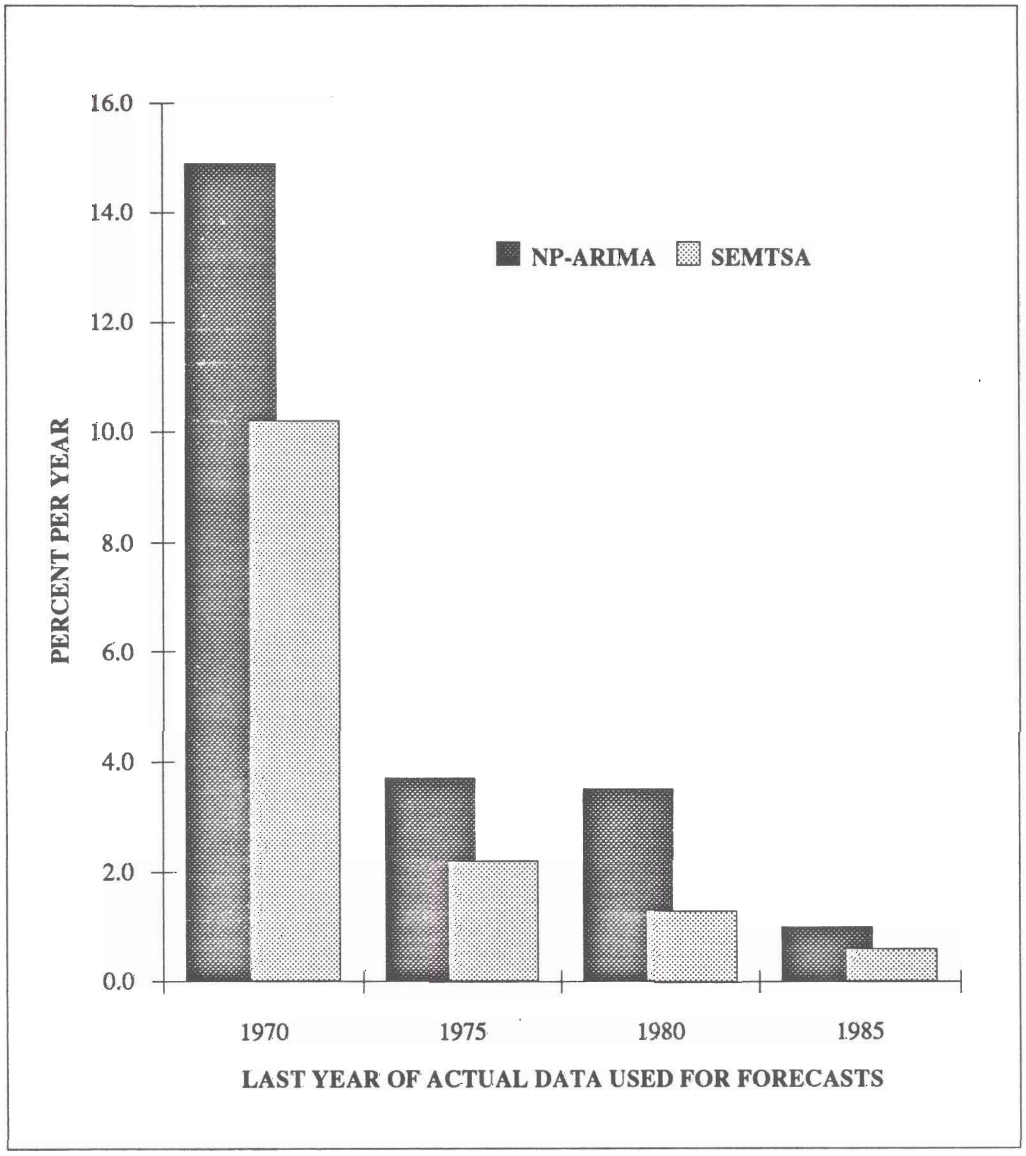


FIGURE 5
SEMTSA FORECASTS OF ANNUAL SALES OF ELECTRICITY

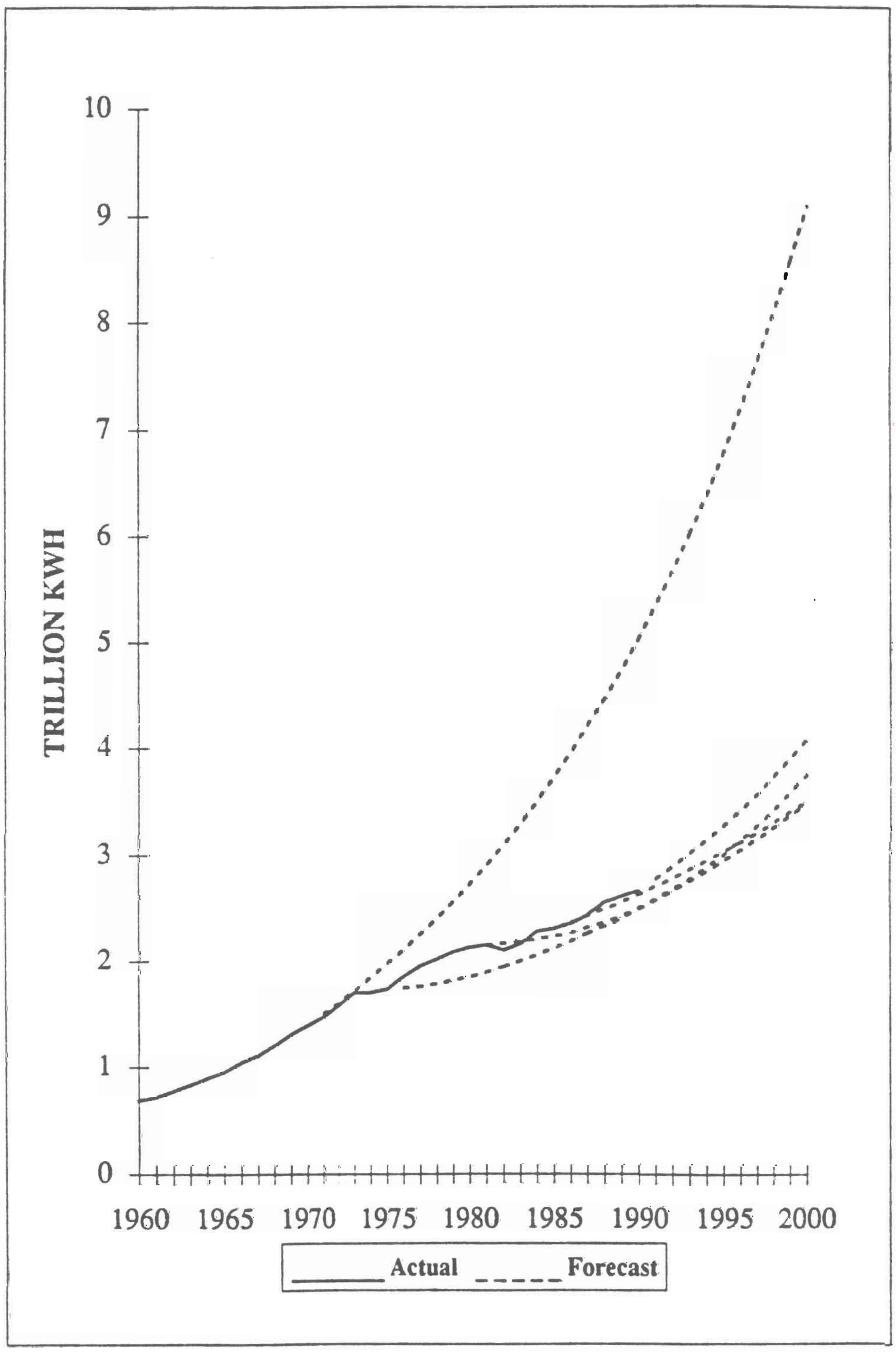


FIGURE 6
SEMTSA FORECASTS OF REAL GNP

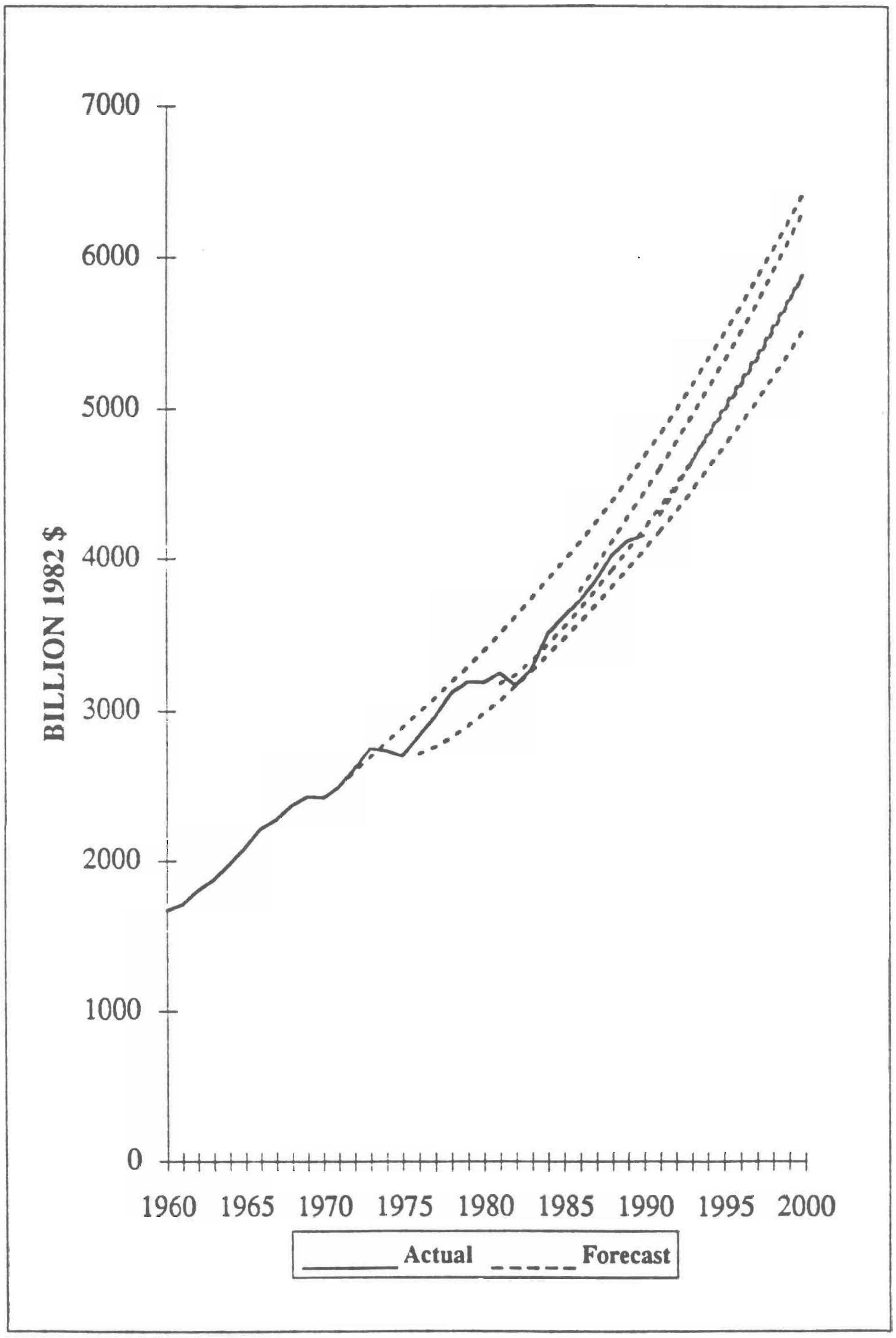


FIGURE 7
SEMTSA FORECASTS OF THE REAL PRICE OF ELECTRICITY

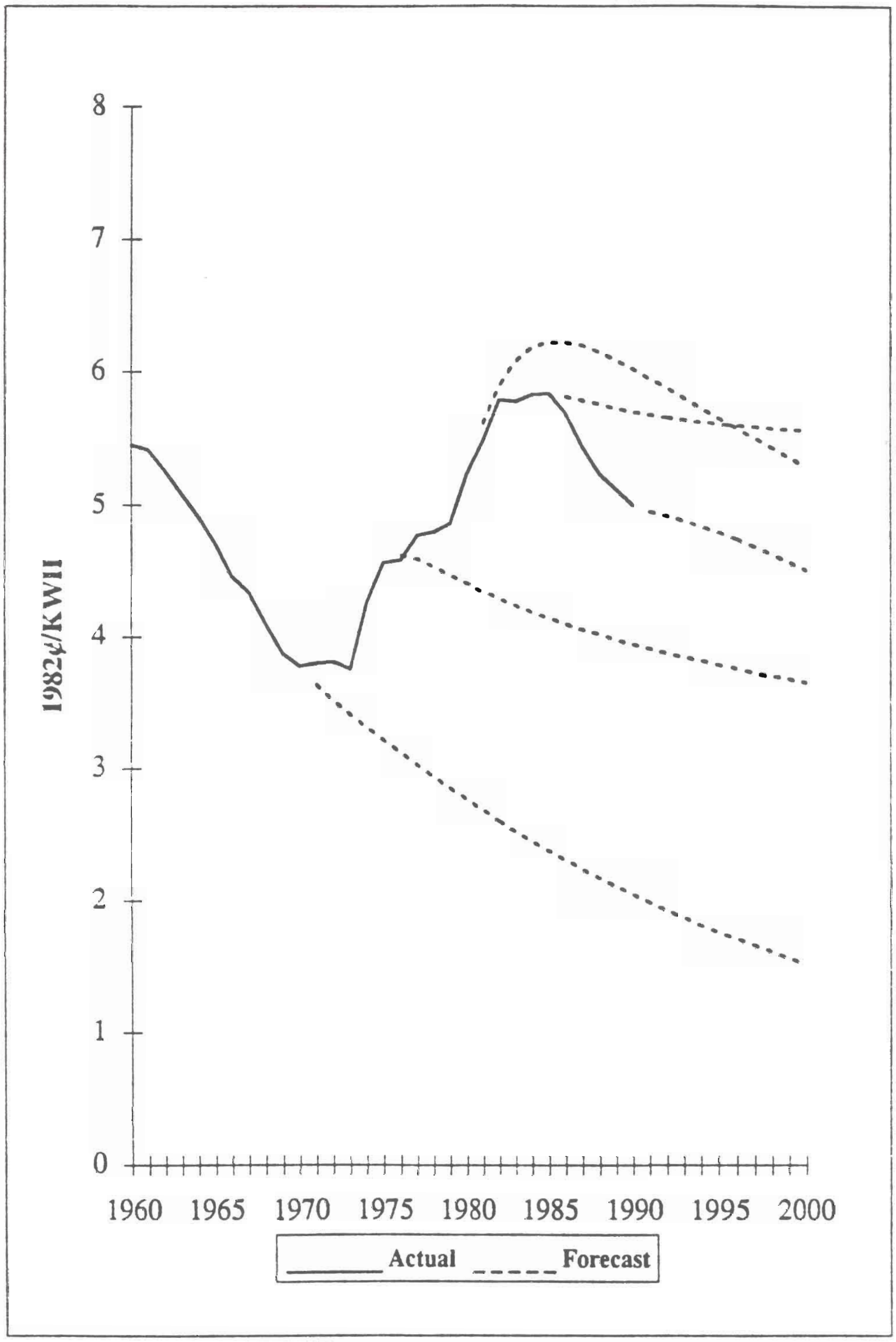


FIGURE 8
SEMTSA FORECASTS OF THE REAL PRICE OF FUEL OIL

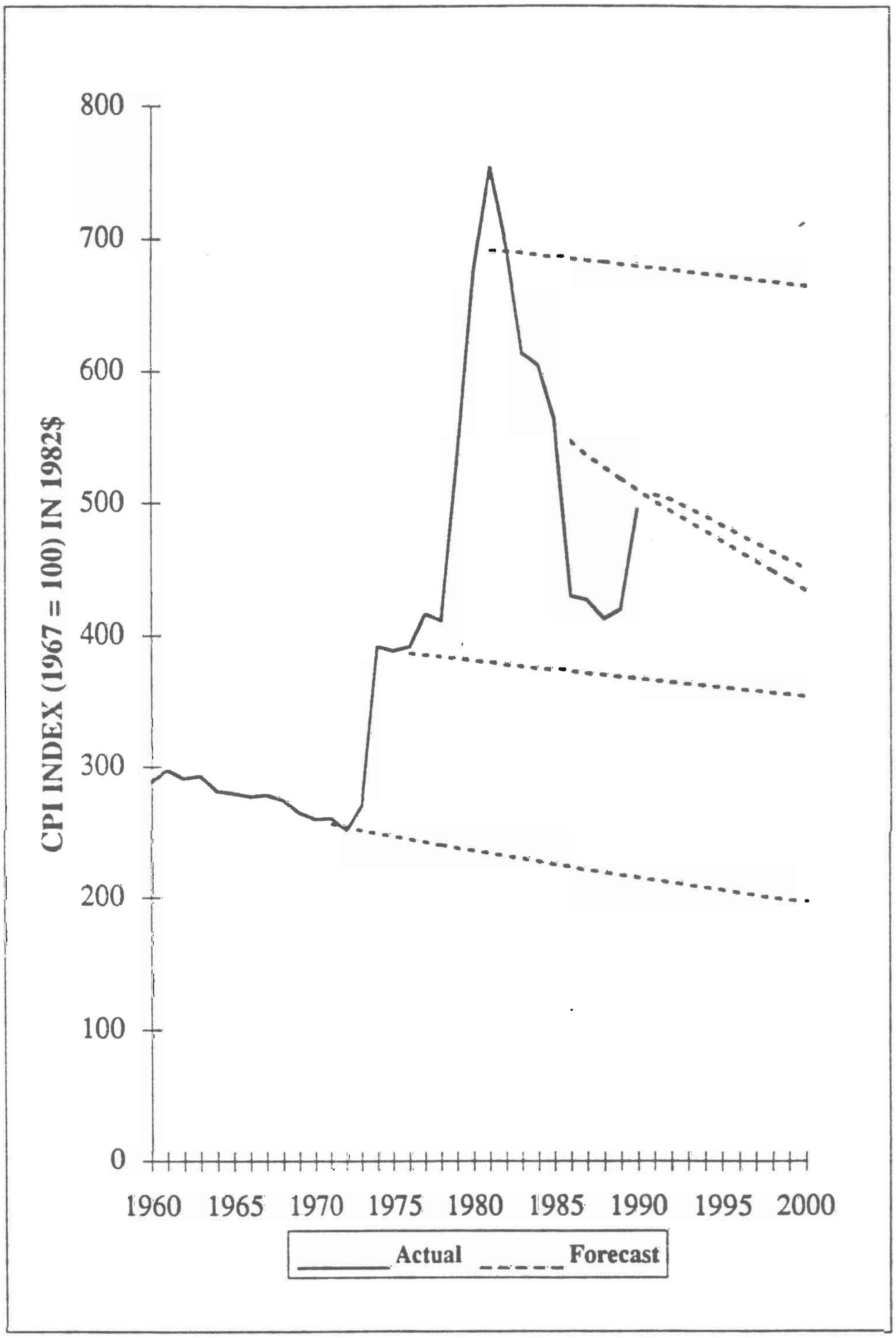


Table A1. Notation, Variable, Units, and Sources.

Notation	Variable	Units	Source
GNP	Gross National Product	Billions of 1982 Dollars	Economic Report of the President and recent issues of the Survey of Current Business
KWH	Total Sales (Demand) to Ultimate Customers	Millions of Kilowatt-Hours	Edison Electric Institute Statistical Yearbook
REL	Total Revenue from Ultimate Customers	Thousand of Current Dollars	Edison Electric Institute Statistical Yearbook
PEL	Real Price of Electricity	Cents/Kilowatt, 1982 Dollars	Calculated as (SDOL/S)/D
PNG	Real Price of Utility Piped Gas to All Urban Consumers[a]	Index (1967=100) in 1982 dollars	CPI Detailed Reports Bureau of Labor Statistics, U.S. Department of Labor[b]
PFO	Real Price of Fuel Oil to all Urban Consumers[a]	Index (1967=100) in 1982 dollars	CPI Detailed Reports Bureau of Labor Statistics, U.S.Department of Labor[b]
D	Implicit Price Deflator for GNP	Index, 1982=100	Economic Report of the President and recent issues of the Survey of Current Business

[a] Pre 1978, Consumer Prices are for Urban Wage Earners and Clerical Workers.

[b] Also 1978 edition of Handbook of Labor Statistics.

Table A2. The Full Sample Data Characteristics. 1947-1990

Variable	Units	Mean	Std. Dev.	Range	Symbol
GNP	1982$ x 10^9	2404.7	917.3	1067-4157	GNP
KWH	KWH x 10^9	1317.8	795.0	217-2667	KWH
REL	Current dollars x 10^9	51.5	57.1	3.9-175.5	REL
PEL	CENTS (1982) per KWH	5.43	1.13	3.76-8.01	PEL
PFO	Deflated (1982=100) Index (1967=100)	375.0	130.5	251-754	PFO
PNG	Deflated (1982=100) Index (1967=100)	341.5	83.9	258-558	PNG
D	Index (1982=100)	0.540	0.334	0.157-1.315	D
Log GNP	Log(1982$ x 10^9)[a]	7.710	0.401	6.97-8.33	LGNP
Log KWH	Log (KWH x 10^6)[a]	13.848	0.770	12.29-14.80	LKWH
Log PEL	Log (PEL)[a]	1.67	0.204	1.32-2.08	LPEL
Log PFO	Log (PFO)[a]	5.88	0.301	5.53-6.63	LPFO
Log PNG	Log (PNG)[a]	5.81	0.222	5.55-6.32	LPNG

[a] As used in regressions

Table A3. The Mean Value of Variables for Sub Samples, 1947 to Year Shown

Variable[a]	1970	1975	1980	1985
GNP	1691	1857	2033	2203
KWH	671.2	837.6	1009.4	1161.9
REL	11.0	15.0	23.40	37.18
PEL	5.80	5.49	5.40	5.44
PFO	295.59	298.56	326.01	367.04
PNG	294.19	289.97	301.80	328.82
D	0.302	0.337	0.395	0.477
LGNP	7.402	7.485	7.564	7.636
LKWH	13.272	13.450	13.606	13.734
LPEL	1.733	1.674	1.660	5.853
LPFO	5.687	5.694	5.762	5.853
LNG	5.683	5.668	5.704	5.772

See Tables A1 and A2 for units and definitions.

Table A4. Correlation of Logarithms of Variables

Period/ Variable	Variable				
	LKWH	LGNP	LPEL	LPFO	LPNG
1947 - 1990					
LKWH	1.000				
LGNP	0.987	1.000			
LPEL	-0.658	-0.566	1.000		
LPFO	0.589	0.633	0.132	1.000	
LPNG	0.556	0.628	0.231	0.879	1.000
1947 - 1985					
LKWH	1.000				
LGNP	0.992	1.000			
LPEL	-0.723	-0.659	1.000		
LPFO	0.555	0.614	0.141	1.000	
LPNG	0.457	0.522	0.257	0.900	1.000
1947 - 1980					
LKWH	1.000				
LGNP	0.993	1.000			
LPEL	-0.891	-0.864	1.000		
LPFO	0.371	0.413	0.064	1.000	
LPNG	0.149	0.179	0.277	0.826	1.000
1947 - 1975					
LKWH	1.000				
LGNP	0.993	1.000			
LPEL	-0.977	-0.973	1.000		
LPFO	-0.179	-0.182	0.351	1.000	
LPNG	-0.643	-0.693	0.724	0.328	1.000
1947 - 1970					
LKWH	1.000				
LGNP	0.989	1.000			
LPEL	-0.991	-0.988	1.000		
LPFO	-0.636	-0.659	0.678	1.000	
LPNG	-0.515	-0.589	0.606	0.443	1.000

Table A5. Correlation of First Difference Logarithms of Data

Period/ Variable	LKWH	Variable LGNP	LPEL	LPFO	LPNG
1947 - 1990					
LKWH	1.000				
LGNP	0.492	1.000			
LPEL	-0.758	-0.327	1.000		
LPFO	0.012	-0.219	0.232	1.000	
LPNG	-0.315	-0.408	0.562	0.244	1.000
1947 - 1985					
LKWH	1.000				
LGNP	0.499	1.000			
LPEL	-0.839	-0.332	1.000		
LPFO	-0.064	-0.225	0.245	1.000	
LPNG	-0.517	-0.471	0.571	0.175	1.000
1947 - 1980					
LKWH	1.000				
LGNP	0.483	1.000			
LPEL	-0.854	-0.300	1.000		
LPFO	-0.237	-0.297	0.321	1.000	
LPNG	-0.494	-0.426	0.613	0.374	1.000
1947 - 1975					
LKWH	1.000				
LGNP	0.522	1.000			
LPEL	-0.846	-0.308	1.000		
LPFO	-0.081	-0.248	0.189	1.000	
LPNG	-0.435	-0.658	0.535	0.220	1.000
1947 - 1970					
LKWH	1.000				
LGNP	0.432	1.000			
LPEL	-0.780	-0.120	1.000		
LPFO	0.470	-0.145	-0.611	1.000	
LPNG	-0.187	-0.593	0.261	-0.063	1.000

Table A6 Ex Post Forecast Accuracy
Kilowatt Hours

	Period							
	70-90		75-90		80-90		85-90	
	SEMTSA	NP ARIMA	SEMTSA	NP ARIMA	SEMTSA	NP ARIMA	SEMTSA	NP ARIMA
RMSE	1.14	1.63	0.20	0.36	0.11	0.27	0.04	0.06
PRMSE	10.21	14.91	2.23	3.75	1.31	3.54	0.62	1.04
MAD	0.85	1.23	0.19	0.28	0.09	0.26	0.03	0.05
Theil's U	0.22	0.29	0.05	0.07	0.02	0.55	0.01	0.01
UB	0.56	0.57	0.90	0.54	0.43	0.88	0.25	0.64
UV	0.42	0.42	0.01	0.44	0.49	0.10	0.53	0.29
UC	0.02	0.01	0.09	0.03	0.08	0.02	0.22	0.07

Table A7 Ex Post Forecast Accuracy
Gross National Product (SEMTSA)

	Period			
	70-90	75-90	80-90	85-90
RMSE	295.51	173.09	63.59	146.19
PRMSE	1.81	1.30	0.53	1.46
MAD	243.62	152.11	58.75	123.48
Theil's U	0.04	0.03	0.01	0.02
U_B	0.64	0.77	0.22	0.71
U_V	0.27	0.0	0.08	0.21
U_C	0.09	0.23	0.70	0.07

Table A8 Ex Post Forecast Accuracy
Price of Electricity

	Period			
	70–90	75–90	80–90	85–90
RMSE	2.42	1.14	0.60	0.45
PRMSE	9.82	5.14	3.45	3.60
MAD	2.12	0.98	0.49	0.38
Theil's U	0.31	0.12	0.05	0.04
U_B	0.77	0.07	0.68	0.70
U_V	0.01	0.03	0.0002	0.30
U_C	0.23	0.24	0.32	0.001

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