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An Econometric Study of Electricity Demand by Manufacturing Industries

Hui S. Chang
Wen S. Chern

Prepared for the
U.S. Nuclear Regulatory Commission
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CONTENTS

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ABSTRACT

This report presents an econometric model of electricity demand for the Standard Industrial Classification (SIC) three-digit manufacturing industries in the United States. Previous studies on the demand for electricity by manufacturing industries are reviewed briefly. The specification of the model, which consists of a demand and a price equation, is discussed. Estimation, dynamic-simulation, and forecasting results for each of the 16 industry groups (15 SIC three-digit industries plus one for all remaining industries) are presented.

The econometric results show that the demand and the price equations, specified and estimated, reflect reasonably well the dynamic adjustment processes of industrial demand for electricity. The estimated equations are generally satisfactory; the estimated coefficients all have the predicted signs, and most are statistically significant. Estimated results reveal that there are substantial interfuel substitutions in manufacturing industries.

The dynamic simulation results show that the model predicts very well the electricity demand and price of manufacturing industries in the sample period. The forecast results show that electricity demand of all the manufacturing industries as a whole would grow at an average rate of 3.7% per year from 1977 to 1995, with the forecasted growth rates varying substantially among industries.

Impact multiplier analyses reveal that the model is sensitive to changes in exogenous variables and that the use of a single-equation approach cannot reflect correctly the effects of changes in exogenous variables on electricity demand. Finally, in the study of factors affecting the price elasticity of demand for electricity, it is found that the price elasticity of industrial demand (in absolute value) is positively related to electricity intensiveness, the price of electricity, and the speed of adjustment, and is negatively related to the elasticity of demand with respect to the value added.

I. INTRODUCTION

The growing interest of economists in energy research has generated a large number of studies directed toward the demand for and supply of energy in different markets. Most of the existing studies of electricity demand have focused primarily on the residential sector. Industrial demand has received much less attention. The studies on electricity demand prior to 1975 were previously surveyed by Taylor.[1] Since the Taylor paper, we have noted a few more studies on industrial demand for electricity by Chern,[2] Halvorsen,[3] Chern et al.,[4] Hock,[5] and Faruqui.[6]

Existing studies on industrial demand for electricity have mostly used cross-sectional census data for the manufacturing sector as a whole or for individual Standard Industrial Classification (SIC) two-digit industries. Since different industries use different production processes, highly aggregated electricity-demand studies cannot adequately deal with such important questions as price responsiveness and interfuel substitution, nor can the estimated equations be used to forecast future demand for electricity at a more disaggregated level. Furthermore, in the economic literature, no attempt has been made to explain variation of estimated price elasticities among industries. Since the variation in price elasticity of demand has important implications for the growth of industrial demand for electricity, it is essential to identify factors which may affect such a variation.

The major objectives of this study are as follows. A demand function and a price equation for the study of electricity demand are specified and estimated for 16 U.S. manufacturing industries (15 at the SIC three-digit level plus one for all remaining industries), using the time-series data 1959 to 1976. The estimated results are further validated by sample-period simulation tests. The estimated equations are then used to forecast future demand for electricity from 1977 to 1995 and to analyze effects of changes in exogenous variables on the demand for electricity of the SIC three-digit manufacturing industries. Finally, the variations in the estimated price elasticity of demand among the industries studied are examined. It is hoped that the behavior of the demand functions may be revealed more accurately, and the future demand for electricity by manufacturing industries may be forecast in more detail, by using more disaggregated data. It is also hoped that the effects of changes in exogenous variables on the demand for electricity, and reasonable explanations for the variation in the price elasticities of demand among the industries, can be at least partially explored in this study.

In Section II, previous studies are reviewed briefly. A dynamic demand function and a price equation (which takes into account the effect of the decreasing block-rate pricing practice of electric utilities) are specified in Section III. In Section IV, empirical results obtained from three-stage least squares are presented and discussed. Performances of the models are then examined in Section V. In Section VI, forecasts on the demand for electricity by industry from 1977 to 1995 are provided. In Section VII, the effects of changes in exogenous variables on electricity demand obtained from multiplier simulation analysis are reported. The variation in the estimated price elasticities of demand among industries is then investigated in Section VIII. The final section presents a brief summary and conclusion.

II. REVIEW OF PREVIOUS STUDIES

Fisher and Kaysen[7] studied the demand for electricity of ten SIC two-digit manufacturing industries, using state data obtained from the 1956 Census of Manufacturers. The demand for electricity of an industry was expressed as a function of value added and the price for electricity paid by an industry. A log-linear form was used for the demand function. They found that six of the ten industries had a significant and negative coefficient for the price variable and that the estimated coefficients for value added were positive for all industries and were significant statistically for all but two industries. Their estimated price elasticity of demand ranges from -0.78 for food and kindred products to -2.60 for chemicals and allied products.

Based on the methodology of Fisher and Kaysen,[7] Anderson[8] analyzed the demand for electricity of the U.S. primary-metal industry. Like Fisher and Kaysen, Anderson employed state cross-sectional data for the years 1958 and 1962 in his estimation. A log-linear functional form was also used in Anderson's study. Similar to the results of Fisher and Kaysen, his estimated price elasticity of demand for electricity of the primary-metal industry is negative, substantial (-1.94), and significant statistically.

Mount, Chapman, and Tyrrell[9] analyzed both short-run and long-run electricity demand for three classes of consumers: residential, commercial, and industrial. A model was estimated by using pooled cross-section and time-series data consisting of annual observation on 47 contiguous states from 1947 to 1970. A Koyck distributed lag structure was used for dynamic adjustments. The long-run price elasticity of demand of the industrial sector was found to be -1.74 when the instrumental-variable approach was used and -1.82 when the ordinary least-squares approach was adopted. Although they used data across 47 states, their industrial model is highly aggregate, since both manufacturing and nonmanufacturing sectors were included. The major shortcoming in their industrial model is the problem of specification. They used virtually the same set of variables for residential, commercial, and industrial demand.

Lacking industrial output as an explanatory variable, the industrial model is not properly specified. Consumers' income and population, which were included as variables, have only indirect effects through the determination of industrial output.

Lyman[10] also analyzed the demand for electricity of three classes of consumers: residential, commercial, and industrial. Lyman used firm data, as opposed to national and state aggregate as had been used in previous studies. He also used nonlinear demand functions of the type considered by Box and Cox[11] and Zarembka.[12] The purchase of electricity per customer was specified as a function of electricity price, gas price, an index of other prices, and other economic, demographic, and climatic variables. The model was estimated for each customer class, using a data set consisting of annual observations for the years 1959 to 1968 on 67 investor-owned electric utilities. Lyman found that the price elasticity of demand of industrial customers was -1.40.

Wilson[13] adopted a model similar to that of Fisher and Kaysen[7] and extended the model to include 15 SIC two-digit industries. The 1973 census data for standard metropolitan statistical areas were used to estimate the parameters. This estimate of the price elasticity of demand ranges from -0.76 for leather products to -2.23 for chemicals and allied products. He tried two alternative price variables: a typical industrial rate in a set market area and an average price for each industry in each market. Both price variables performed well, but the average price proved to be significant for more industries than the other did. Wilson concluded that price is, in most instances, a significant determinant of the consumption of industrial power. He also noted that in five of the six groups having high electric intensiveness, the price variable was significant. This implies that those industries shown to be sensitive to electricity price variation are those with the highest propensity to consume electricity.

In the United Kingdom, Baxter and Rees[14] published an earlier study derived from a cost-minimization model that evaluated industrial demand for electricity as an exponential function of input prices and output level. They adopted coal consumption as a variable to reflect technological changes over time. A geometric lag model was fitted by ordinary least squares to quarterly British data over the 1954-1964 period. Their findings suggest that electricity demand is highly responsive to changes in output level and fuel technology but relatively unresponsive to price. This insignificant price effect is in sharp contrast to the results obtained from the previously cited studies using U.S. data. They also found that the assumption of the unitary elasticity of electric demand with respect to output is generally inappropriate when time-series data were used.

Chern[2] specified and estimated demand functions for electricity of 16 major energy-consuming industries at the SIC three-digit level in the United States. This is the first attempt to study the electricity demand of manufacturing industries at a more disaggregated level. Electricity consumption was assumed to be functionally related to the level of industrial output, the price of electricity, prices of other forms of energy, and other pertinent variables. Both static and dynamic demand models were employed in this study. The static model was designed to investigate the short-run demand response for each of the 16 industries, and was estimated by the use of annual data from 1958 through 1971. Results show that electricity price and output were significant variables in all industries. The estimated short-run price elasticity of demand ranged from -0.40 to -1.66 among the industries investigated. A dynamic demand model with geometric lag was also specified and estimated by methods of pooling time-series and cross-industry data. The 16 industries were separated into two groups on the basis of whether or not gas was found to be a significant substitute for electricity in the static model. The industrial demand for electricity was shown to be price-elastic in the long run, ranging from -1.01 to -1.98.

More recently, Halvorsen[3] estimated demand functions for electricity of the three classes of consumers in the United States: residential, commercial, and industrial. Halvorsen's major contribution is the specification of price equations to take into account the declining block-rate pricing practice of the electric industry and hence eliminate the simultaneous-equation problems due to the interdependence between electricity consumption and price. His equations were estimated with cross-sectional data for 48 contiguous states in 1969. He found that the estimated own-price elasticity of demand of the industrial sector was -1.24 when typical electric bill variables were used in the demand equation and -1.40 when cost variables were used. Halvorsen also projected the growth of the demand for electricity in 1990 under alternative assumptions on future prices, using estimated elasticities of demand. He found that the industrial demand would grow at a compound annual rate of 4.16% per year if the real electricity price would decrease by 0.5% per year from the past rate. It would grow at 3.14% if the real price would stay constant, and would grow at 1.86% if the real price would increase by 1% per year.

Most recently, Hock,[5] in a report prepared for the Electric Power Research Institute, estimated the demand for electricity of seven major energy-consuming manufacturing industries at the SIC two-digit level. A linear equation was estimated for each industry, using time-series data for the period 1954-72. The equations, modified as appropriate for changes in technology, were used to project electricity consumption of the manufacturing sectors through 1995. His estimated results showed that the short-run price elasticity of demand ranged from -0.036 to -0.909 among the industries investigated. According to his forecast, the total electricity consumption of the manufacturing sectors would grow from 4.4% to 4.9% per year if there was no change in the real price of electricity in the forecasted period, and from 3.9% to 4.4% if the real price grew at 1% per year. In this study, no dynamic adjustment processes were considered for the estimation of the demand function. In addition, the interdependence between the price of electricity and the quantity purchased due to the declining block-rate pricing of the electric industry was not taken into account.

Most recently, Chern et al.[4] studied the demand for electricity for three sectors of users: residential, commercial, and industrial. A simultaneous-equation model, which contains a dynamic demand function in log-linear form and a price equation in quadratic form, is estimated for each sector and each of the nine Bureau of Census geographical regions. One important feature of the model is in the specification of the price equation, in which it is assumed that the average electricity price over the three sectors is equal to overall electricity cost plus a profit margin. The model was estimated by using pooled time-series (1955 to 1974) and cross-section (over the states in a region) data. Both two-stage and three-stage least-squares techniques were applied to the three sectors jointly. Results showed that the estimated long-run price elasticity of demand varied substantially among regions, ranging from -0.04 in the Middle Atlantic region to -0.87 in the West North Central region for the industrial sector. In this study, the estimated equations were also used to forecast electricity demand and price by state, by region, and by sector from 1974 to 1990, using three scenarios. They forecast that the demand for electricity of the industrial sector as a whole in the United States would grow at an annual rate of 4.3% according to the base case, 4.1% according to the high-price case, and 4.5% according to the low-price case.

This review of previous studies reveals progress over time in the study of the demand for electricity of manufacturing industries. For example, more disaggregated SIC three-digit data were first used by Chern[2] to reflect more correctly the heterogeneity of manufacturing industries. A price equation was first specified by Halvorsen[3] to correct the simultaneous-equation problems due to the declining block-rate pricing practice of the electric industry. Moreover, a more logical relationship between electricity price and costs of generating and distributing electricity was first specified by Chern et al.[4] for the price equation. In addition, dynamic models are now commonly used for time-series data to reflect partial adjustment processes of the demand for electricity. No effort, however, has been made to estimate a dynamic demand function simultaneously with a logical price equation by using the more disaggregated SIC three-digit data and hence combining all the recent progress in the estimation of the demand for electricity of manufacturing industries. One major contribution of our study is, therefore, to estimate a dynamic demand function and a price equation simultaneously for 16 SIC three-digit manufacturing industries. It is hoped that the electricity demand functions of manufacturing industries can be estimated more accurately and that their future demand can be forecast more reliably by combining the past advances in this area.

III. THE MODEL

As mentioned above, to study demand for electricity of manufacturing industries in the United States, a model containing two simultaneous equations can be specified for each manufacturing industry at the SIC three-digit level. The first is a dynamic demand equation, which reflects the behavior of the firm in cost minimization. The second is a price equation which takes into account the declining block-rate pricing practice of the electric industry. These two equations can be explained as follows.

A. The Demand Equation

The demand for electricity is a derived demand. Electricity is used as a direct and/or indirect input for industrial production. Plant lighting, cooling, and heating are examples of indirect usages of electricity; operation of machinery and application in various chemical processes are direct usages in manufacturing processes. Electricity is not consumed by itself; it is utilized along with other capital stock, such as appliances and machinery. It is now well known that, under such circumstances, the effect of a change in explanatory variables on electricity demand depends on the lifetime of electric durables. In the short run, electricity customers often can adjust only the utilization rate of existing capital stock, while in the long run both utilization rate and capital stock can be altered. In modeling demand for electricity, both short-run and long-run responses of quantity demand to changes in explanatory variables must be taken into account.

In a static framework, the behavior of a firm can be described by either a cost-minimization or profit-maximization model. The equilibrium conditions of the two models, as is well known, converge under the assumption of perfect competition. The adoption of either of the two models would, therefore, make no theoretical difference if perfect competition is assumed. In this study, the cost-minimization model is adopted, since the input demand function derived from it reflects more directly the relationship between input and output of a firm than does the profit-maximization model. Solving the first-order conditions for cost minimization, the derived input demand equation has the following general form:

$$y_j = F(Q, P_1, P_2, \ldots, P_j, \ldots, P_J), \; j = 1, 2, \ldots, J, \qquad (1)$$

where y_j is the quantity demanded for the jth input, Q is the output level, and P_j is the price of jth input.

The preceding theorization is conventional and is known as the theory of the derived input demand. The aggregate input demand is obtained by summing the demand of all the individual firms concerned. The functional form in Eq. (1) can be obtained by a direct link to the forms of the production function. But such an explicit derivation requires a well-specified underlying production function which is usually unknown. Consequently, some conventional functional forms, such as linear, double-logarithmic, or semilogarithmic form, are often assumed. For simplicity, a double-logarithmic form is used for the demand function in this study.

Electricity is the input to be investigated. From the preceding derivation, electricity demand of an industry can be expressed as a function of the final output of the industry, the price of electricity, and prices of other inputs, such as labor, capital, and substitute fuels. In order to take into account the dynamic effect of explanatory variables, the following partial adjustment model is specified:

$$\ell n E_t^* = \alpha_0 + \alpha \ell n Z_t + u_t , \qquad (2)$$

where

E_t^* = the equilibrium level of electricity demanded in period t,

Z_t = a vector of demand determinants,

u_t = the error term,

α_0 = an unknown scalar,

α = a vector of unknown coefficients, and

$$\frac{E_t}{E_{t-1}} = \left(\frac{E_t^*}{E_{t-1}}\right)^{\lambda} ,$$

or

$$\ell n\ E_t - \ell n\ E_{t-1} = \lambda\left(\ell n\ E_t^* - \ell n\ E_{t-1}\right) , \quad (3)$$

where E_t and E_{t-1} are the observed electricity demand in periods t and t - 1 respectively, and λ, a positive fraction, is the coefficient of adjustment to be determined.

Substituting (3) into (2) yields the following familiar expression:

$$\ell n\ E_t = \lambda\alpha_0 + \lambda\alpha\ \ell n\ Z_t + (1 - \lambda)\ \ell n\ E_{t-1} + \lambda u_t . \quad (4)$$

Under this specification, $\lambda\alpha$ is a vector of short-run elasticities, and α is a vector of long-run elasticities.

B. Problems of Declining-Block-Rate Pricing and the Price Equation

The practice of declining-block-rate pricing by electric utilities implies that electricity customers are faced with a series of electricity rates rather than a single price per kilowatt-hour, and furthermore, the price of electricity is negatively related to the amount consumed. As discussed by Taylor,[1] such a practice leads to theoretical problems such as discontinuous demand and Engel curves, and multiple tangencies of the budget constraint and indifference curves in estimating demand functions. Due to the interdependency between the quantity demanded and price, ordinary least-squares estimates of the demand function are biased and inconsistent.

Theoretically, under declining-block-rate pricing, marginal price should be used in the demand function. The use of marginal price, however, has some empirical problems. First, data on marginal price are difficult to construct (see Taylor[1]), especially in the industrial sector. Second, customers are usually unaware of the marginal price they pay for each incremental unit of electricity. Individual customers are usually influenced by expected price, which behaves more like average price. Finally, the use of average price makes forecasting much easier than the use of marginal price because, as in this model, only estimates of future electricity generation costs are needed to make forecasts of average price. Usually, there is more information available to forecast the system's costs than sectoral marginal prices. Recent studies by Halvorsen,[3,15] Chern,[16] and Wilder and Willenborg[17] showed that the bias introduced by the problems of simultaneity can be avoided or reduced greatly if average price is endogenized in the model. In this study, average price is used in a simultaneous-equation model.

The formulation of the price equation follows the approach used by Chern et al.[4] To begin with, under declining-block-rate pricing, the price of electricity paid by a customer in a given year is determined by the amount of electricity consumed and other relevant variables, given the current rate schedule:

$$PE^j = f^j(E^j, X; R) \tag{5}$$

where

PE^j = the average price of electricity paid by customer j in a given year,

E^j = the quantity purchased by customer j in the same year,

X = a vector of other relevant variables,

R = current electricity rates.

Since the rate schedule is presumably related to the underlying cost structure, Eq. (5) may be written as

$$PE^j = f^j(E^j, X, K) \ , \tag{6}$$

where K is the average cost of producing and distributing electricity over all power generating plants in the year concerned. It is obvious that the slope, $\partial f^j/\partial E^j$, in (6) must be negative because of declining-block-rate pricing.

Equation (6) represents the theoretical model for the price equation. However, data are available only by groups of customers (i.e., by industry in the case of industrial demand rather than by individual firms). While the negative relationship between average price and quantity consumed always holds at the micro level (i.e., for an individual firm), it does not always hold between aggregate price and aggregate demand. An increase in the quantity demanded by an industry may result in an increase in the aggregate average price if the increase is consumed by marginal users or low-level users who are paying higher rates than others. Hence the relationship between the average price (PE_i) paid by an industry and the quantity (E_i) consumed in a given year is characterized by

$$PE_i = f_i(E_i, X, K) , \tag{7}$$

in which the slope, $\partial f_i/\partial E_i$, may be either positive or negative.

To further specify Eq. (7) for empirical estimation, it is assumed that a utility sets rate schedules such that, based on their expectations, total revenue in a year will exceed costs by some set rate of profit per unit of electricity which will satisfy utility regulatory commissions. This assumption can be expressed as

$$\widehat{PE} = K + m , \tag{8}$$

where $\widehat{PE}$ is the expected average price of the utility in a year, over all sectors and industries, based on rate schedules; K is the overall average cost; and m is the profit margin. If $\hat{E}_i$ represents the utility's expected consumption by industry or sector i, given rate schedules, then by using (7) the expected average price for the industry or sector, $\widehat{PE}_i$, can be expressed as

$$\widehat{PE}_i = f_i(\hat{E}_i, X, K) . \tag{9}$$

The expected share of the ith industry or sector in the total consumption of electricity can be expressed as

$$\hat{S}_i = \hat{E}_i/\sum_i \hat{E}_i ,$$

and hence

$$\widehat{PE} = \Sigma \hat{S}_i \widehat{PE}_i . \tag{10}$$

Combining (8), (9), and (10) yields

$$\sum_i \hat{S}_i f_i(\hat{E}_i, X, K) = K + m . \tag{11}$$

Differentiating (11) with respect to K, one obtains

$$\sum_i \hat{S}_i \frac{\partial f_i}{\partial K} = 1 . \tag{12}$$

But if (12) holds for all possible $\hat{S}_i$ (note that $\sum_i \hat{S}_i = 1$) in different years, then $\partial f_i/\partial K$ must be equal to 1 for all i; hence K must appear additively in Eqs. (7) and (9). By setting $\widehat{PE}_i$ and $\hat{E}_i$ equal to PE_i and E_i, we have

$$PE_i = f(E_i, X, K) - g(E_i, X) + K . \tag{13}$$

This shows that changes in costs are passed on to all industries in order to maintain profit margin.

Given Eq. (13), it remains to specify an estimable form for $g(E_i,X)$. One possibility is to specify $g(E_i,X)$ as a log-linear form as in the demand equation (4). However, this cannot be done, since data for PE_i - K are negative in some cases, while $g(E_i,X)$ can only be positive to be expressed in logarithm.

A second possibility is to specify $g(E_i,X)$ as a quadratic form. This specification was previously used by Chern et al.[4] However, in this study, when the estimated quadratic-form price equations are used to solve the system of equations, solutions for six of the industries under investigation could not converge and hence were not obtainable. Attempts to solve the problem by normalization of the quantity variable of an industry in the price equation by the value added of the industry were not successful. Therefore, the demand equation was finally specified in the following linear form so that the solutions for all of the industries can be obtained:

$$PE_i - K = \beta_0 + \beta_1 E_i + \beta_2 X . \quad (14)$$

As discussed in Chern et al.,[4] the aggregate price equation may have a negative or positive slope coefficient for the quantity variable. When the aggregate price curve has a negative slope (as estimated for most industries), a linear price curve would definitely intersect with the curvilinear demand curve twice (unless it does not intersect with the demand curve at all). However, since the estimated slope parameters all have a small magnitude, indicating a very flat price curve, only one intersection occurs in the observed and forecasted price-quantity space; thus only one solution is obtained. The reason for the lack of convergence under the specification of a quadratic price equation is that the estimated price curve did not intersect with the estimated demand curve; thus no solution was obtainable.

Equation (14) is the basic structure of the price equation in this study. Two variables, the ratio of industrial sales to total sales of electricity (RE) and a dummy variable (D), are the variables in X. RE is included to account for the possible scale effect of changes in the ratio of industrial sales to total sales of electricity on the price of electricity paid by industries; it generally holds that transmission and distribution costs per kilowatt-hour sold are lower for industrial sales than for residential and commercial sales. D is used to account for the possible effect of the energy crisis on the profit margin of the utility industry and is defined later.

IV. EMPIRICAL ESTIMATION AND RESULTS

A. The Variables and Data

According to the discussion in the preceding section, the demand and price equations for an industry are specified as

$$\ell n\, E_t = \alpha_0 + \alpha_1\, \ell n\, E_{t-1} + \alpha_2\, \ell n\, \frac{PE_t}{WPI_t} + \alpha_3\, \ell n\, \frac{PO_t}{WPI_t} + \alpha_4\, \ell n\, \frac{PG_t}{WPI_t} + \alpha_5\, \ell n\, \frac{PC_t}{WPI_t} + \alpha_6\, \ell n\, \frac{V_t}{WPM_t} + \alpha_7\, \ell n T + \alpha_8\, \ell n\, \frac{W_t}{WPI_t} + \alpha_9 D_t + u_{1t}\ , \qquad (15)$$

$$PE_t - K_t = \beta_0 + \beta_1 E_t + \beta_2 RE_t + \beta_3 D_t + u_{2t}\ , \qquad (16)$$

where

- E_t = electricity purchased and generated in year t,
- PE = average price of electricity,
- PG = average price of natural gas,
- PC = wholesale price index of coal,
- PO = average wholesale price of heavy fuel oil,
- V = value added in manufacturing,
- W = wage rates of manufacturing workers,
- K = overall average costs of generating, transmitting, and distributing electricity,
- RE = the ratio of industrial sales to total sales of electricity,
- WPI = wholesale price index of intermediate materials and supply,
- WPM = wholesale price of industrial commodities,
- T = time trend variable expressed in years,
- D = dummy variable having the value of 1 for 1974 to 1976, and zero otherwise,
- u_1, u_2 = disturbance terms, assumed to be normally and independently distributed.

It is noted that V is used as a proxy for industrial output; T is used to reflect the effect of technological changes on the demand for electricity; and D is used to account for possible effects of the 1973 energy crisis on the demand and price of electricity.

The present study investigates 15 major energy-consuming manufacturing industries at the SIC three-digit level (Table 1) and the remaining manufacturing industries grouped together. The selection of 15 industries is based on availability of data. Nevertheless, these industries represent the major users of electricity, and they, together, accounted for 53% of electricity consumption in the manufacturing sector in 1976. Annual national data from 1959 to 1976 are used to estimate the coefficients for the equations. Detailed definitions of the variables and sources of the data are given in Appendix A.

B. Regression Results

Ordinary least squares (OLS), two-stage least squares (2SLS), and three-stage least squares (3SLS) were used to estimate Eqs. (15) and (16) for each of the 16 industries. For most industries, the signs of estimated coefficients are not sensitive to alternative estimation methods. Generally, 3SLS estimates have smaller standard errors than OLS or 2SLS estimates. Since OLS is biased and inconsistent in a simultaneous-equation model, and 2SLS is less efficient than 3SLS, the 3SLS results should be more appropriate, and thus those estimates are used for dynamic simulation and forecasting. The estimates for the demand equations by 3SLS are given in Table 2 and those for the price equations are given in Table 3. The estimates obtained from OLS and 2SLS are given in Appendix B for comparison.

As can be seen from Table 2, the estimated coefficients of the lagged dependent variable, the price of electricity, and the value added all have the expected signs for all industries, and, in most cases, they are statistically significant at the 0.05 level. The retention of other variables, however, is based on the plausibility of the signs and statistical significance of the estimated coefficients.

Table 2 also reveals that natural gas is a significant substitute for electricity in SIC 203, 225, 262, 263, 282, 322, 324, 331, 332, 371, and other industries. Coal is a significant substitute for electricity

Table 1. Identification of the manufacturing industries analyzed

SIC code	Description	Electrical consumption[a] in 1976: 10^{12} kWh	Electrical consumption[a] in 1976: percent of total
	All industries	634.9	100.0
203	Canned, cured, and frozen foods	5.2	0.8
204	Grain-mill products	6.1	1.0
221	Weaving mills, cotton	4.2	0.7
225	Knitting mills	3.9	0.6
262	Paper mills, except building paper	20.9	3.3
263	Paperboard mills	10.2	1.6
281A	Industrial chemicals, exclusive of the Department of Energy's three uranium enrichment plants	74.9	11.8
282	Plastic materials and synthetics	16.8	2.6
291	Petroleum refining	26.3	4.1
322	Glass and glassware; pressed or blown	6.5	1.0
324	Cement, hydraulic	9.1	1.4
331	Blast furnace and basic steel products	54.6	8.6
332	Iron and steel foundries	11.4	1.8
333	Primary nonferrous metals	66.8	10.5
371	Motor vehicles and equipment	17.7	2.8
	All remaining industries	300.2	47.3

[a]Does not include the amount of self-generated electricity consumed.

Source: U.S. Bureau of the Census, *Annual Survey of Manufacturers, 1976*, Washington, D.C., June 1978.

Table 2. Industrial demand equations estimated by three-stage least squares[a]

(the dependent variable = ℓnE)

Industry SIC code	Constant (α_0)	ℓn E_{-1} (α_1)	ℓn $\frac{PE}{WPI}$ (α_2)	ℓn $\frac{PG}{WPI}$ (α_3)	ℓn $\frac{PC}{WPI}$ (α_4)	ℓn $\frac{PO}{WPI}$ (α_5)	ℓn $\frac{V}{WPI}$ (α_6)	T (α_7)	ℓn $\frac{W}{WPI}$ (α_8)	D (α_9)	R^2
203	6.415*	0.435*	-1.464*	0.456*		1.018*	0.276*			-0.420*	0.995
	(2.47)	(0.08)	(0.18)	(0.09)		(0.30)	(0.06)			(0.12)	
204	0.674	0.849*	-0.229			0.323	0.100			-0.118	0.989
	(1.45)	(0.10)	(0.20)			(0.35)	(0.04)			(0.12)	
221	2.198	0.253*	-0.128*			0.403*	0.463*			-0.164*	0.994
	(0.61)	(0.05)	(0.07)			(0.11)	(0.03)			(0.04)	
225	3.210	0.460*	-1.002*	0.441*		0.622*	0.484*	-0.051*		-0.290*	0.997
	(2.05)	(0.05)	(0.20)	(0.08)		(0.28)	(0.11)	(0.02)		(0.11)	
262	9.102	0.287*	-0.858*	0.473*	0.067*		0.227*	0.039*		-0.057*	0.996
	(1.90)	(0.10)	(0.14)	(0.05)	(0.03)		(0.06)	(0.01)		(0.02)	
263	3.499	0.125*	-0.209	0.175*	0.111*		0.709*			0.017	0.994
	(2.06)	(0.08)	(0.20)	(0.06)	(0.03)		(0.10)			(0.03)	
282	3.041	0.650*	-0.575*	0.367*	0.121*		0.325*			-0.026	0.996
	(1.46)	(0.05)	(0.19)	(0.08)	(0.05)		(0.06)			(0.03)	
281A	3.576*	0.457*	-0.216				0.429*			0.060	0.962
	(1.22)	(0.09)	(0.16)				(0.09)			(0.05)	
291	0.518	0.823*	-0.033				0.182*			0.041	0.996
	(0.85)	(0.04)	(0.08)				(0.04)			(0.02)	
322	9.968*	0.168*	-1.069*	0.315*	0.111*		0.212		0.743*	0.049*	0.999
	(1.68)	(0.08)	(0.19)	(0.07)	(0.04)		(0.12)		(0.09)	(0.02)	
324	1.652	0.202*	-0.088	0.166*			0.815*	0.071*		0.059*	0.966
	(1.84)	(0.10)	(0.12)	(0.05)			(0.11)	(0.01)		(0.02)	
331	1.223	0.543*	-0.434*	0.524*	0.244*		0.387*			-0.084*	0.986
	(1.52)	(0.05)	(0.14)	(0.08)	(0.03)		(0.06)			(0.03)	
332	-0.848	0.768*	-0.464	0.465*			0.377*	-0.112*		-0.107*	0.988
	(3.77)	(0.10)	(0.42)	(0.19)			(0.13)	(0.04)		(0.05)	
333	5.327*	0.367*	-0.649*		0.249*		0.596*			0.078	0.967
	(1.74)	(0.08)	(0.23)		(0.07)		(0.11)			(0.05)	
371	11.877*	0.095	-1.506*	0.714*			0.459*			0.042	0.982
	(2.59)	(0.09)	(0.31)	(0.13)			(0.06)			(0.05)	
Other industries	7.394*	0.431*	-0.894*	0.490*	0.056		0.313*			-0.024*	0.994
	[illegible]	(0.11)	(0.22)	(0.07)	(0.05)		(0.11)			(0.03)	

[a] R^2 from 3SLS cannot be interpreted in the same way as R^2 from OLS. In addition, when 3SLS is used, R^2 is not calculated by the statistical analysis system used in this study; therefore, R^2 from OLS is given as a reference to the goodness of fit.

*Indicates that the coefficient is significant at the $\alpha = 0.05$ level. Figures in parentheses are estimated standard errors.

Table 3. Industrial price equations estimated by three-stage least squares[a]

(the dependent variable = PE - K)

Industry SIC code	Constant	E	RE	D	R^2
203	318.969 (618.27)	-0.089* (0.03)	-836.117 (1165.92)	-257.641* (23.66)	0.957
204	1915.427* (732.31)	-0.135* (0.04)	-3686.428* (1228.31)	-276.520* (29.31)	0.895
221	-66.626 (86.61)	0.033* (0.01)	-2129.036* (194.59)	-115.337* (22.92)	0.853
225	504.613 (416.92)	-0.101* (0.02)	-1496.740 (833.61)	-259.613* (38.70)	0.897
262	226.421 (556.68)	-0.008 (0.01)	-1911.149* (933.36)	-374.298* (30.18)	0.888
263	-994.931 (552.09)	-0.001 (0.01)	513.691 (963.75)	-391.60* (33.93)	0.911
282	-136.123 (413.04)	-0.005 (0.01)	-1355.840 (781.60)	-282.534* (25.56)	0.864
281A	3536.647* (1352.60)	-0.017 (0.01)	-7642.809* (2197.70)	-389.483* (61.15)	0.780
291	-722.132 (694.59)	0.001 (0.01)	-340.766 (1199.11)	-382.018* (29.11)	0.905
322	340.453 (424.07)	-0.025 (0.02)	-2103.375* (780.24)	-174.857* (31.77)	0.709
324	-210.958 (354.95)	-0.003 (0.02)	-1051.013* (493.98)	-249.691* (23.85)	0.831
331	707.159* (227.58)	0.003* (0.001)	-451.025 (379.73)	-271.075* (16.23)	0.934
332	-314.671 (211.22)	-0.002 (0.01)	-125.428 (397.44)	-185.691* (18.40)	0.913
333	-2138.487* (623.97)	0.007* (0.003)	1208.365 (1082.96)	-752.103* (50.84)	0.630
371	12.023 (375.57)	0.001 (0.01)	-1143.810 (646.32)	-45.854 (24.93)	0.633
Other	-274.950 (640.62)	-0.0003 (0.0007)	-136.219 (1163.33)	-272.994* (32.32)	0.878

[a]Same as for Table 2.

*Indicates that the coefficient is significant at the $\alpha = 0.05$ level. Figures in parentheses are estimated standard errors.

in SIC 262, 263, 282, 322, 331, and 333, while oil is a significant substitute in SIC 203, 221, and 225, and labor is a significant substitute in SIC 322. The time variable is significant in the equations for four industries, implying that technological changes have caused more use of electricity in the production process of SIC 262 and 324 and less use for SIC 225 and 332. The coefficients for the dummy variable are negative and significant at $\alpha = 0.05$ for only six industries (SIC 203, 221, 225, 262, 331, and 332). This coefficient is positive and significant for SIC 322 and 324, and insignificant for the remaining eight industry groups. Even though the interpretation of this coefficient is subject to some degree of uncertainty, the results seem to suggest a mixed result of the industries' efforts to conserve energy during the post-oil-embargo period.

Table 3 reveals that the coefficient for electricity consumption (E) in the price equation varies considerably among industries. For three industries (SIC 203, 204, and 225) the estimated coefficient for E is negative and significant at $\alpha = 0.05$; for another two industries (SIC 291 and 371) it is positive and insignificant; for three other industries (SIC 221, 331 and 333) it is positive and significant; for the remaining eight industries it is negative and insignificant. These results conform with the discussion in Section II that the negative relationship between price and the quantity of electricity demand does not always hold at the aggregate level, since the increase in the quantity demanded at the macro level might be consumed by marginal users and low-level users who are paying higher rates than others. The coefficients for the dummy variables in the price equations are negative and significant for all industries, indicating that the energy crisis may have reduced the profit margins of the utility industry. As suggested by Joskow and MacAvoy,[18] the decrease in profit margin of the utility industry may result from the regulatory lag, which usually causes price increases to lag behind cost increases.

The estimated short-run and long-run elasticities of demand with respect to price, the value added, and the speed of adjustment are summarized in Table 4. The estimated short-run price elasticity of demand

Table 4. Estimated short-run and long-run elasticities of demand for electricity

Industry SIC code	Own-price elasticities		Value-added elasticities		Speed of adjustment
	Short run	Long run	Short run	Long run	
203	-1.46	-2.59	0.28	0.49	0.57
204	-0.23	-1.52	0.10	0.66	0.15
221	-0.13	-0.17	0.46	0.62	0.75
225	-1.00	-1.86	0.48	0.90	0.54
262	-0.86	-1.20	0.23	0.32	0.71
263	-0.21	-0.24	0.71	0.81	0.88
282	-0.58	-1.46	0.32	0.82	0.40
281A	-0.22	-0.40	0.43	0.79	0.54
291	-0.03	-0.19	0.18	1.03	0.18
322	-1.07	-1.29	0.21	0.25	0.83
324	-0.09	-0.11	0.82	1.02	0.80
331	-0.43	-0.95	0.39	0.85	0.46
332	-0.46	-2.01	0.38	1.61	0.23
333	-0.65	-1.02	0.60	0.94	0.63
371	-1.51	-1.66	0.46	0.51	0.91
Other	-0.89	-1.57	0.31	0.55	0.56

ranges from -0.03 for SIC 291 (petroleum refining) to -1.51 for SIC 371 (motor vehicles), indicating a substantial variation of industries' responsiveness to price changes. The short-run elasticity of demand with respect to the value added ranges from 0.100 for SIC 204 (grain-mill products) and 0.212 for SIC 322 (glass and glassware) to 0.709 for SIC 263 (paperboard mills) and 0.815 for SIC 324 (cement). This probably reflects the fact that, in the short run, electricity is used more as a direct or variable input (e.g., for the operation of machinery and applications in chemical processes, etc.) in SIC 263 and SIC 324 and more as an indirect or fixed input (e.g., for plant heating and cooling, etc.) in SIC 204 and SIC 322. Another explanation for the variation in the elasticity with respect to the value added may be related to technological changes over the sample period. If an industry has become more efficient in using electricity as a result of technological innovation, value-added elasticity would be smaller. The estimated coefficients of adjustment, λ (equals: $1 - \alpha_1$), ranges from 0.91 for SIC 371 to 0.15 for SIC 204, indicating that different industries adjust their demand for electricity at different speeds to changes in explanatory variables.

The estimated long-run price elasticity of demand ranges from -0.17 for SIC 221 (weaving mills) to -2.59 for SIC 203 (canned foods), and the long-run value-added elasticity ranges from 0.32 for SIC 262 (paper mills) to 1.61 for SIC 332 (iron and steel). A comparison of estimates with those of previous studies presented in Section II reveals that the estimated price elasticities of demand have a wider range of variation among different industries than those of previous studies. This is primarily because the industries are more disaggregated in this study. When industries are aggregated into SIC two-digit industries, the elasticities are likely to be averaged out and hence have a smaller range of variation.

V. PERFORMANCE OF THE MODEL

An econometric model must be validated before it is used for forecasting. One of the important tests for validation is the sample-period simulation test (see Howrey, Klein, and McCarthy,[19] and Christ[20]). In sample-period simulation tests, the actual values of predetermined variables and the estimated coefficients are used to generate the estimated values of endogenous variables. The difference between the actual and the estimated values of an endogenous variable is the error of simulation. Mean absolute percentage error (MAPE) and mean square percentage error (MSPE) are two of the most common summary measures, suggested by Klein,[21] for examining the performance of econometric models. They are defined as:

$$\text{MAPE} = \left(\frac{1}{n} \sum_{1}^{n} \frac{|\hat{y}_i - y_i|}{y_i} \right) \cdot 100 \, , \tag{17}$$

$$\text{MSPE} = \frac{1}{n} \left(\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{{y_i}^2} \right)^{1/2} \cdot 100 \, , \tag{18}$$

where n = the number of time periods simulated,

y_i = the actual value of the endogenous variable in period i,

$\hat{y}_i$ = the estimated or model-produced value of the endogenous variable in the same period.

Testing the performance of an econometric model is not the same procedure as that used for examining the performance of a forecaster who uses an econometric model. A forecaster must obtain information on the future values of exogenous variables of the model from some extraneous sources. The forecaster's performance depends to a great degree on the ability to obtain accurate information on the future values of the exogenous variables. In addition, a forecaster may believe that the model is going to make an incorrect forecast because of dynamic simulation results or because of recent events not included in the model and may adjust some of its constant terms in a way that he or she believes can improve the forecast. Consequently, subjective judgments are often added to a model's forecasts. In conducting the sample-period simulation test, however, the model is treated as an impersonal structure, and no subjective adjustments should be made on the equations. In addition, the total result should not depend on the ability of the forecaster to predict correctly the future values of exogenous variables, since the actual values of the exogenous variables are applied to the model. Therefore, the results from a sample-period simulation test cannot be used as a yardstick for the performance of forecasting. It only demonstrates how closely the equations track the behaviors of the endogenous variables in the sample period.

Since the model estimated in this study is a nonlinear simultaneous-equation system, the system cannot be solved in closed form. Solutions to this system of equations are obtained by the Gauss-Seidel iterative approach.[22] Estimated equations for each of the 16 industries are validated by the sample-period simulation. Results (given in Table 5) show that the estimated equations for most of the industries perform satisfactorily. In terms of MAPE, 13 out of the 16 industries register an error of less than 5% in estimating electricity consumption. Only industries 225 (knitting mills), 281A (chemicals), and 333 (primary nonferrous metals) have MAPE of slightly greater than 5%. In terms of MSPE, 11 industries register an average error of less than 5% and the other five industries an error of slightly greater than 5%. In the dynamic simulation of the electricity price over the sample period, 14 industries have an MAPE of less than 5%, and 13 industries have an MSPE of less than 5%. Only SIC 333 and 281A produce relatively greater simulation errors, registering MAPE of 7.70% and 12.75% and MSPE of 9.27% and 15.10%, respectively.

Table 5. Performance of the models according to sample-period simulations[a]

Industry SIC code	Simulation of electricity consumption		Simulation of electricity price	
	MAPE	MSPE	MAPE	MSPE
203	4.88	6.59	3.33	4.08
204	2.21	2.77	3.19	3.81
221	2.03	1.29	1.71	2.18
225	5.22	7.47	4.64	7.59
262	3.94	4.93	4.20	5.25
263	2.17	2.52	3.74	4.79
281A	5.20	7.63	12.75	15.10
282	2.50	3.05	3.33	4.02
291	1.37	1.84	4.26	4.82
322	3.52	4.60	3.03	3.97
324	1.91	2.27	2.94	3.76
331	1.97	2.43	1.64	2.03
332	3.65	4.70	1.44	1.80
333	5.46	7.14	7.70	9.27
371	4.05	6.05	1.74	2.96
All others	2.71	4.03	2.48	3.11

[a]MAPE is the mean absolute percentage error and is calculated according to Eq. (17). MSPE is the mean square percentage error and is calculated according to Eq. (18).

VI. FORECASTED RESULTS

The estimated structural equations presented in Section IV are used for forecasting electricity demand and price. This section presents the assumptions used for forecasting all the results for the period 1977 to 1995.

A. Assumptions

Assumptions on the growth rates of future values of exogenous variables are based on projections made by public or private sources. The future growth rates of the value added by industry are taken from the projection of the Office of Economic Impacts, Energy Information Administration, U.S. Department of Energy.[23] The future growth rates of the wholesale price index (WPI) are derived from the forecasts of Data Resources, Inc.[24] Future growth rates of fuel prices (PO, PG and PC) are obtained from the Department of Energy.[25] Specifically, the DOE projections for the series C (medium supply and demand) with oil import price of $23.50 are used. The future costs of electricity production are calculated as the weighted average of projected fuel costs and operating and maintenance costs.[26] The real wage rate is assumed to grow at the rate of 2% per year in the forecast period. The ratio of industrial sales of electricity to total sales of electricity (RE) is assumed to follow the decreasing trend in the sample period. Detailed assumptions about the future growth rates of exogenous variables in the model are given in Tables 6 and 7.

It should be noted that the assumptions on exogenous variables are taken from different sources. Thus there may be inconsistencies among different projections. However, both sets of the projections of value added and fuel prices are based on DRI's long-range forecasts of general economic activities. Any error introduced by these inconsistencies should be relatively small.

Before forecasts are made, the constant term for 5 out of the 32 equations are further adjusted to reflect potential effects of revisions

Table 6. Projected annual growth rates (in percent) of real value added by industry, 1977 to 1995[a]

SIC code	1977-1980	1980-1985	1985-1990	1990-1995
203	2.85	3.46	2.40	2.12
204	2.85	3.46	2.40	2.12
221	3.86	4.28	3.78	3.82
225	3.86	4.28	3.78	3.82
262	2.92	4.36	3.60	3.45
263	2.90	4.36	3.60	3.45
281A	5.60	6.32	5.92	5.00
282	5.60	6.32	5.92	5.00
291	1.55	1.20	0.28	0.02
322	4.27	2.99	2.98	2.54
324	4.27	2.99	2.98	2.54
331	2.77	3.57	3.38	3.50
332	2.77	3.57	3.38	3.50
333	2.77	3.57	3.38	3.50
371	3.86	4.28	3.78	3.82
Other	3.86	4.28	3.78	3.82

[a]The annual growth rates of value added are forecast for SIC two-digit industries only.

Source: Office of Economic Impacts, Energy Information Administration, U.S. Department of Energy. These projections are not published information and thus should be regarded as preliminary.

Table 7. Projected annual growth rates (in percent) of exogenous variables, 1977 to 1995

Variables[a]	1977-1980	1980-1985	1985-1990	1990-1995
WPI	6.00	6.00	5.00	4.10
PO	8.86	7.86	8.79	7.95
PG	13.54	13.54	8.48	8.50
PC	7.79	7.79	6.12	5.37
W	8.00	8.00	7.00	6.10
K	8.47	7.50	6.46	6.46
RE	-1.00	-0.50	-0.25	0.00

[a]All variables except RE are expressed in current dollars.

of published data, to correct possible bias of estimated equations, or to take into account possible changes in the behavior of the equation beyond the sample period. These adjustments were determined according to the "residual check" from dynamic simulations, a procedure commonly used in econometric forecasting (see Chang,[27] and Adams and Rowe[28]). The magnitudes of the constant adjustments are relatively small in comparison with the magnitudes of the endogenous variables. For example, the constant adjustments for the price equations of SIC 221 and 282 in 1977 are both +\$0.60 per 10^3 kWh, which represent about 2% and 3.1%, respectively, of the forecasted prices (\$22.49 and \$19.09) for these industries in 1977.

B. Baseline Forecasting

Based on assumptions on future growth rates of exogenous variables, electricity demand and price are forecast for each of the 16 manufacturing industries for the period 1977 to 1995. The quantities demanded by the industries are then summed to obtain the total demand of the manufacturing industries. Forecasted results for electricity consumption in 1980, 1990, and 1995 and average annual growth rates of consumption and deflated price are given in Table 8. From the table, one can see that the demand for electricity of the manufacturing industries as a whole will grow continuously in future years, increasing from 699,506 million kWh in 1976, to 803,437 million kWh in 1980, to 1,193,000 million kWh in 1990, and to 1,391,436 million kWh in 1995. This represents a growth of 3.7% per year, which is substantially lower than the 5.09% growth per year during the period 1959-1974, but is higher than the 2.06% growth per year during the two years (1974-1976) right after the energy crisis.

This forecast of 3.7% annual growth rate for the period from 1977 to 1995 falls reasonably close to those of previous studies. As reviewed in Section II above, Chern et al.[4] predicted that the demand for electricity of the industrial sector as a whole would grow at an annual rate of 4.3% from 1974 to 1990 according to the base-price scenario, 4.1% according to the high-price scenario, and 4.5% according to the low-price scenario. These forecasts have recently been further revised using the recent DOE

Table 8. Forecasted electricity consumption in 1980, 1990, and 1995 and average annual growth rates of consumption and price 1977 to 1995, by industry

Industry	Electricity consumption[a]				Average annual growth rate of demand (1977 to 1995) %	Average annual growth rate of deflated price (1977 to 1995) %
	1976 (actual)	1980	1990	1995		
SIC 203	5,199	5,226	8,247	10,261	3.7	2.8
SIC 204	6,895	7,809	10,866	14,100	3.8	2.4
SIC 221	4,373	4,827	6,758	8,168	3.3	3.6
SIC 225	3,927	4,537	7,969	10,823	5.5	2.8
SIC 262	33,545	36,656	54,797	64,279	3.5	4.2
SIC 263	20,276	22,507	32,128	37,276	3.3	4.3
SIC 281A	87,152	103,997	190,140	243,370	5.6	3.5
SIC 282	19,323	21,711	37,433	45,963	4.7	3.9
SIC 291	30,763	33,327	36,014	35,800	0.8	4.2
SIC 322	6,498	7,091	9,195	9,994	2.3	3.4
SIC 324	9,533	11,484	17,380	20,581	4.1	3.3
SIC 331	62,400	72,793	138,557	180,758	5.8	3.9
SIC 332	11,455	14,403	29,395	41,162	6.9	2.7
SIC 333	72,681	80,577	104,200	120,153	2.7	7.6
SIC 371	17,745	19,660	25,520	26,729	2.2	2.6
Other industries	307,741	356,829	484,938	522,017	2.8	3.0
All industries	699,506	803,437	1,193,500	1,391,436	3.7	3.5

[a]Electricity consumption is expressed in million kWh.

projections of fuel prices as used in this study. The revised projections, as reported by Chern and Just,[29] show that the annual growth rates of industrial demand for electricity from 1974 to 1990 are 4.0%, 3.6%, and 4.4% for the base price, low-price, and high-price cases, respectively. Halvorsen[3] projected that the industrial demand for electricity would grow at an annual rate of 4.16% through 1990 if the real price of electricity decreased by 0.5% per year from the past price, 3.14% if the real price stayed the same, and 1.86% if the real price increased by 1% per year. Hock[5] estimated that the electricity consumption of the manufacturing sectors that they studied would grow from 4.4% to 4.9% per year through 1990 if there was no change in the real price of electricity, and 3.9% to 4.4% if the real price would grow at 1% per year. The forecasts of this study for the demand for electricity of the manufacturing sectors as a whole are slightly lower than those of Chern et al.[4] and higher than those of Halvorsen[3] and Hock,[5] taking into account the 3.5% average annual growth rate of the real electricity price forecast in this study.

The forecasted growth, however, varies substantially among industries, ranging from highs of 5.04% and 4.88% per year for SIC 203 (processed foods) and 281 (chemicals) to lows of 0.8% and 2.2% for SIC 291 (petroleum refining) and 317 (motor vehicles and equipments). The differences in the future growth rates of electricity demand primarily reflect the differences among industries in the growth rates of value added as projected by the Office of Economic Impacts, U.S. Department of Energy, and the future interfuel substitutions due to changes in relative prices of fuels. For example, as shown in Tables 6 and 7, real value added for SIC 332 (iron and steel foundries) is projected to increase at an annual rate of 3.5% per year, and the price of natural gas is projected to increase as much as 13.54% per year from 1977 to 1985 and 8.48% per year from 1985 to 1995. Since natural gas is a significant substitute for electricity in SIC 332, the increase in output and the substitution of electricity for natural gas will raise the demand for electricity of this industry by an annual rate of 6.8% during the forecast period. On the other hand, for SIC 291, since the projected annual growth in the real value added declines from 1.55% for 1977 to 1980 to 0.02% for 1990 to 1995, the forecasted annual growth rate of electricity demand of this industry is only 0.8% per year for the period 1977 to 1995.

Forecasts on the growth rates of the deflated price indicate that the electricity price will continue to grow at a faster rate than the general price level; the deflated price will grow at a positive average annual rate from 1977 to 1995 for all of the industries studied. Forecasted growth rates of the electricity price also vary substantially among industries, ranging from high annual rates of 7.6% and 4.3% for SIC 333 (nonferrous metals) and 263 (paperbound mills) to low rates of 2.4% and 2.6% for SIC 204 (grain-mill products) and 371 (motor vehicles and equipment). The variation in the projected growth rates of the price among industries generally reflects the correction of past inequalities in the electricity price; those industries which consumed electricity at a relatively low price in the past are facing a relatively higher growth of the price, and those which paid relatively higher prices can expect the price to rise relatively slowly in the future. Since SIC 333 (primary nonferrous metals) has been paying at a very low price relative to other industries, the future increase in the electricity price paid by this industry is expected to rise at a much higher rate than for other industries.

VII. MULTIPLIER SIMULATION ANALYSIS

In studies of input demand, the quantity demanded is often regressed on the price of the input, the quantity of output, the prices of other inputs, and other relevant variables. The estimated coefficients are then used to indicate the effect of changes in output or prices of other inputs on the demand for the input. Such a single-equation approach, as used by Halvorsen,[3] assumes implicitly that the price of the input is constant, while other exogenous variables change. This is an improper assumption in the case of electricity demand. Changes in exogenous variables in the demand equation first directly affect the quantity of electricity demanded. Because of the decreasing block-rate pricing practice of the electric industry, changes in demand will then affect average price of electricity. The resultant change in price will again influence demand. Without taking into account the interdependence between demand and price, estimated effects of changes in exogenous variables on electricity demand will be erroneous.

To obtain correct effects of changes in exogenous variables, the demand and price equations should be used simultaneously to perform two dynamic simulations. In the first simulation, a set of values for the exogenous variables, which represents the researchers' best prediction on future courses of the variables, is used. In the second simulation, the same values of exogenous variables are used, except that one of them is changed by a given amount. The differences between the two sets of simulated results represent the effect of a change in the exogenous variable on the endogenous variables. In order to avoid the influence of units of measurements, the effects (impact multipliers) are usually expressed in terms of elasticities. That is, an exogenous variable is changed by a given percentage, and resultant changes in endogenous variables are also expressed in percentages.

The effects of an increase in three exogenous variables on the industrial demand for electricity are reported here. Table 9 shows the effects of a 10% increase in the price of natural gas, the value added, and the cost of generating and distributing electricity in 1977 on the industrial demand for electricity in 1980, 1990, and 1995. As shown in

Table 9. Effect of a 10% increase in the values of exogenous variables in 1977 on future electricity demand (percentage change in electricity demand)

Industry's SIC code	Increase in gas price			Increase in value added			Increase in generation, transmission, and distribution costs		
	1980	1990	1995	1980	1990	1995	1980	1990	1995
203	12.6	11.4	11.0	6.4	6.6	7.3	-32.4	-29.8	-28.8
204	0.0	0.0	0.0	3.8	8.2	9.0	-9.8	-18.0	-19.0
221	0.0	0.0	0.0	6.0	6.1	6.1	-2.0	-1.8	-1.8
225	10.5	10.7	10.6	11.6	11.8	11.8	-22.8	-21.9	-21.6
262	7.5	7.2	7.0	3.5	3.4	3.3	-16.2	-13.6	-12.9
263	1.9	1.9	1.9	8.0	8.0	8.0	-3.1	-2.6	-2.5
281A	0.0	0.0	0.0	7.4	8.5	8.5	-15.8	-15.5	-14.9
282	8.4	9.7	9.7	10.6	11.2	11.0	-8.5	-8.2	-7.9
291	0.0	0.0	0.0	5.4	9.6	10.0	-1.4	-2.0	-2.0
322	2.6	3.8	3.8	2.7	2.6	2.5	-14.9	-13.2	-12.7
324	2.0	2.0	2.0	10.2	10.2	10.2	-1.3	-1.2	-1.1
331	9.9	10.9	10.9	7.2	7.9	8.0	-9.9	-9.1	-8.8
332	12.3	14.0	14.4	17.0	20.0	20.1	-3.9	-4.0	-4.1
333	0.0	0.0	0.0	7.1	8.3	8.5	-13.7	-10.6	-10.0
371	7.7	7.7	7.8	4.9	4.9	4.9	-16.1	-15.3	-15.1
Other	8.6	8.6	8.8	5.4	5.5	5.6	-16.5	-15.5	-15.1
All manufacturing industries	6.0	6.3	6.3	6.7	7.6	7.8	-13.1	-12.0	-11.4

Table 9, a 10% increase in the price of natural gas in 1977, with growth rates of other variables being held the same, will affect future electricity demand of 11 out of the 16 industries investigated. This is consistent with the finding in Section III that natural gas is an explanatory variable in the demand equations of 11 out of the 16 industries. The demand for electricity of all the manufacturing industries as a whole will increase by 6.0%, 6.3%, and 6.3% in 1980, 1990, and 1995, respectively, because of the rise in the gas price. Individual industries, however, will respond differently to this increase. The demand for electricity in 1995 will be increased by as much as 14.4% (SIC 332 — iron and steel foundries) and 11% (SIC 203 — processed foods) and as little as 2% (SIC 263 — paperboard mills and 324 — hydraulic cement) because of the increase in the gas price. These multiplier simulation results are generally higher than the long-run cross-price elasticities calculated from the estimated coefficients presented in Table 2. For example, the long-run elasticity of electricity demand with respect to the gas price is 0.81 for SIC 203 (processed foods), 0.82 for SIC 225 (knitting mills), and 0.66 for SIC 262 (paper mills) according to the coefficients for the gas price and the speeds of adjustment presented in Table 2; but they are 1.10, 1.06, and 0.70, respectively, according to the impact multipliers presented in Table 9. Similar comparisons apply to most of the other industries, except that the long-run elasticities for SICs 263, 324, and 371 calculated from both approaches differ very little. If the models were simulated for a longer period of time rather than until 1995 only, the multiplier simulation results for the three industries could have been greater than those calculated from the single-equation approach, since in the single-equation approach the long-run effect is the total effect over an infinite period of time. The reason that the single-equation approach generally produces a lower estimate of the impact multiplier is that, as mentioned above, it fails to take into account the interdependence between the electricity price and the quantity demanded.

Table 9 also shows that a 10% increase in the value added of all the manufacturing industries in 1977, with the growth rate and other things being held the same, will raise the demand for electricity of all the manufacturing industries as a whole by 6.7% in 1980, 7.6% in 1990, and 7.8% in 1995. The effects of the increase in the value added on the electricity demand of individual industries will again vary substantially among industries, ranging from a 17.0% rise in 1980, 20.0% rise in 1990, and 20.1% rise in 1995 for SIC 332 (iron and steel foundries) to a 2.7% rise in 1980, 2.6% rise in 1990, and 2.5% rise in 1995 for SIC 322 (glass and glassware). The responsiveness of an industry over time to the increase in the value added depends not only on the short-run elasticity of demand with respect to the value added and the speed of adjustment, but also on the effect of changes in quantity demanded on the price and the length of time simulated. The impact multipliers of the increase in value added calculated from dynamic simulations are again generally higher than those calculated from the short-run elasticity and the speed of adjustment alone.

Table 9 also presents the responses of industries to a 10% increase in generation, transmission, and distribution costs (K) of electricity. An increase in the cost per unit of electricity produced will result in an increase in the price of electricity for industrial customers. The last three columns of Table 9 reveal that a 10% increase in the costs of producing electricity will reduce total electricity demanded by all manufacturing industries as a whole by 13.1% in 1980, 12.0% in 1990, and 11.4% in 1995. The effects on individual industries again vary substantially, ranging from a reduction of 32.4% in 1980, 29.8% in 1990, and 28.8% in 1995 for SIC 203 (processed foods), to a decrease of 1.3% in 1980, 1.2% in 1990, and 1.1% in 1995 for SIC 324 (hydraulic cement). The reason that multiplier elasticities calculated for 1995 are less than those for 1980 and 1990 for many industries is that the price equation is specified in the linear form, implying a decrease in the elasticity of price with respect to demand as demand increases.

The calculated impact multipliers of an increase in electricity cost from dynamic simulations, however, are still greater than those c[illegible]ed from the single-equation approach. For example, according to the short-run price elasticities of demand and the speeds of adjustment presented in Table 2, a 10% increase in the costs of producing electricity will, in the long run, reduce the use of electricity by 25.9% for SIC 203 (processed foods), 15.2% for SIC 204 (grain-mill products), and 1.71% for SIC 221 (cotton weaving mills), while usage reductions calculated from dynamic simulations for 1995 are 28.8%, 19.0%, and 1.8% respectively. These differences are again a result of the fact that the single-equation approach does not take into account the interdependence between electricity consumed and the price; the increase in costs and the price will reduce the demand, and the resultant decrease in the demand will further raise the price and reduce the quantity because of the decreasing-block-rate pricing practice of the electric industry.

VIII. ANALYSIS OF THE VARIATION IN THE PRICE ELASTICITY OF DEMAND

As shown in Table 4, both the short-run price elasticity of demand (SPE) and the long-run price elasticity (LPE) for electricity vary substantially among industries; SPE ranges from -0.13 for SIC 221 to -1.46 for SIC 203, and LPE ranges from -0.17 for SIC 221 to -2.59 for SIC 203. Since these variations have important implications for the growth of industrial demand for electricity, it is important to examine the reasons why SPE and LPE differ among industries.

In order to investigate factors affecting SPE and LPE, several variables have been considered. The first is the electricity intensiveness in production, defined as the ratio of electricity consumption to the value added. The electricity intensiveness varies from a mean of 38.6 kWh per dollar of the value added for SIC 333 to 0.9 kWh per dollar for SIC 203 in the sample period. If an industry is more electricity-intensive in production, the cost of electricity should be relatively more important in the total production costs, and hence the industry may be more responsive to a change in the electricity price. The price elasticity of demand (in absolute value) should therefore be positively related to electricity intensiveness.

The second variable considered is the price of electricity. Similar to electricity intensiveness, the higher the electricity price, the greater should be the share of electricity cost in the total production cost, other things being the same. Hence it may also be expected that the price elasticity of demand (in absolute value) moves in the same direction as the price of electricity.

The third variable, which might affect the price elasticity of demand, is the short-run elasticity of demand with respect to value added (SEV). As mentioned in the Section IV, a higher SEV indicates that electricity is used more as a direct or variable input than as an indirect or fixed input. If an input is variable, it tends to change at the same pace as output changes. Hence the level of output rather than the price of electricity should be the dominant factor affecting the demand for the input. If electricity is used as a fixed input, the output level would not have direct effect on its short-run demand. However, the price of electricity will affect its demand by causing a change in the utilization rate of, say, cooling and heating equipment. The above argument amounts to the conclusion that SPE and LPE (in absolute value) are negatively related to SEV. It is recognized that these two elasticities are related by complex functional forms, and there is no *a priori* reason to believe that the direction of causality is from SEV to SPG. The approach is justified on the basis that the value-added variable is treated as an exogenous variable in the model.

The fourth variable considered is the coefficient of adjustment, λ. If an industry can adjust more swiftly from one year to another to changes in exogenous variables, then the greater should be its response to a change in price on the demand for electricity within a given year. Therefore, λ and SPE should be positively related. However, λ and LPE should not be related, since, in the long run, all adjustments are completed regardless of the speed of adjustment. Other variables, such as the price of natural gas, the ratio of electricity consumption to labor input, the consumption of electricity relative to natural gas, and the electricity price relative to the wage rate, were considered and tried, but they were rejected due to implausible results obtained from regression analysis.

In the study of factors affecting SPE, the estimated values of SPE by industry (shown in Table 2) were regressed on the variables mentioned above. Since the estimated standard errors of SPE are different for different industries, the regressions have the inherent problem of heteroscedasticity. In order to correct for heteroscedasticity, weighted least squares rather than ordinary least squares were used to determine the relevant factors affecting SPE. The best results from weighted least squares obtained from different combinations of the variables mentioned above are as follows:[30]

$$\begin{aligned} SPE_i = & \underset{(-2.16)}{-1.054} + \underset{(1.06)}{0.00003}\,\frac{E_i}{V_i} + \underset{(2.89)}{0.001}\,PE_i - \underset{(-2.39)}{1.234}\,SEV_i \\ & + \underset{(2.69)}{1.161}\,\lambda_i\ , \\ & R^2 = 0.77, \qquad i = 1,2,\ \ldots,\ 16\ , \end{aligned} \tag{19}$$

where SPE_i, SEV_i, and λ_i are the short-run price elasticity of demand in absolute value, the short-run elasticity of demand with respect to value added, and the coefficient of adjustment, respectively, obtained in Section IV for the ith industry; E_i, V_i, and PE_i are the means of the electricity consumption, the value added, and the price of electricity, respectively, for the same industry in the sample period; and values in parentheses are t ratios.

Equation (19) shows that all the coefficients have expected signs, and except the coefficient for (E_i/V_i), they are significant at the $\alpha = 0.05$ level. In order to find out the relative effect of each independent variable on the dependent variable, elasticities have been calculated at the means. It is found that the elasticities of SPE with respect to E/V, PE, SEV, and λ equal 0.16, 2.18, -0.87, and 1.13, respectively, at the means of the variables. Consequently, the price of electricity and the coefficient of adjustment are more important determinants of the short-run price elasticity of demand than are the electricity intensiveness and the short-run elasticity of demand with respect to value added.

To examine factors affecting the long-run price elasticity (LPE), the estimated values of LPE by industry (given in Table 4) were expressed in absolute values and regressed on E_i/V_i, PE_i, and SEV_i. The results obtained from weighted least squares are as follows:[31]

$$LPE_i = \underset{(-1.58)}{-1.269} + \underset{(0.73)}{0.00003}\,\frac{F_i}{V_i} + \underset{(3.15)}{0.002}\,PE_i - \underset{(-1.40)}{0.966}\,SEV_i \ ,$$

$$R^2 = 0.75 \ . \qquad (20)$$

From Eq. (20), one can see that the results obtained for LPE are not far from those obtained for SPE in Eq. (19). All the estimated coefficients in both equations have the same signs and are similar in magnitude. The price of electricity again is the most important factor affecting the variation of the price elasticity of demand among industries.

These findings on the variation in the price elasticity have the following implications: (1) A rise in electricity price will reduce the industrial demand for electricity not only because quantity demanded and price are negatively related, but also because a higher price will make industries more responsive to an increase in price. (2) A high-price policy to conserve electricity is more effective for industries like SIC 262, 263, and 333 because they are more electricity-intensive in production than other industries like SIC 203, 371, and 225. (3) To those industries (e.g., SIC 204 and 291) which use electricity more as an indirect input, a high-price policy to conserve energy should be more effective than to those industries (e.g., SIC 263 and 324) which use electricity more as a direct input. (4) Some industries (e.g., SIC 263, 322, and 371) react more quickly to changes in factors affecting the costs than others (e.g., SIC 204, 291, and 332), and hence their demand for electricity in the short run is more responsive to changes in price.

The analysis conducted here is a two-step regression procedure in which the first step is to estimate a specific structural model; and the second step is to regress the estimates of structural parameters obtained from the first step on a set of explanatory variables. It is noted that the elasticities estimated in the first step are functions of the sample observations. The resulting sampling distributions of the α_i are asymptotically normal under the usual assumptions of the simultaneous-equation model. The properties of the estimator used in the second step are generally not known. Another complication arises because two explanatory variables (SEV and λ) are estimated coefficients obtained from the first-step regression. Thus, these two variables may be correlated to each other, and furthermore, they may be correlated with the error term. Such potential bias associated with Eqs. (19) and (20) deserves further investigation.

IX. SUMMARY AND CONCLUSIONS

In the preceding sections, a dynamic electricity demand model was specified and estimated for the major manufacturing industries at the SIC three-digit level. Estimated results obtained from three-stage least squares are generally satisfactory; the estimated coefficients all have the expected signs and most are statistically significant. The estimated results reveal that there are substantial interfuel substitutions in manufacturing industries, and that the estimated price elasticities of demand, the speeds of adjustment, and the elasticities of demand with respect to the value added, all vary substantially among industries.

Simulation results indicate that the estimated equations all perform well in tracking electricity demand and electricity price of manufacturing industries in the sample period, registering mean absolute percentage error and mean square percentage error of less than 5% for most of the industries studied. Forecasted results show that the electricity demand of all the manufacturing industries as a whole would grow at an annual rate of 3.7% from 1977 to 1995, which is substantially lower than the 5.09% growth per year during the sample period 1959 to 1974, but is higher than the 2.06% annual growth during the three years (1974 to 1976) right after the energy crisis. The forecasted growth rates of individual industries, however, vary substantially among industries, reflecting primarily the differences in the projected growth of the value added.

Multiplier simulation results show that a 10% increase in the price of natural gas in 1977, with other variables remaining unchanged, increases the demand for electricty of all the manufacturing industries by 6.0% in 1980, 6.3% in 1990, and 6.3% in 1995. A 10% increase in the value added of all the manufacturing industries in 1977, other things being the same, raises the demand for electricity by 6.7% in 19[illegible], 7.6% in 1990, and 7.8% in 1995. The same percentage increase in the costs of generating and distributing electricity in 1977, on the other hand, reduces the electricity demand of manufacturing industries by as much as 13.1% in 1980, 12.0% in 1990, and 11.4% in 1995. The effects of changes in exogenous variables on the future demand for electricity will vary considerably among industries, depending on the short-run elasticities, the speed of adjustment, and the relationship between electricity price and demand of each particular industry. It is also demonstrated that, if the single-equation approach were used without taking into account the declining block-rate pricing practice of the utility industry, the estimated effects of changes in exogenous variables on electricity demand would be erroneous.

In the study of factors affecting the price elasticity of industrial demand for electricity, it is found that the price elasticities of demand (in absolute value) are positively related to electricity intensiveness and the price of electricity, and are negatively related to the elasticity of demand with respect to the value added of the industry. Therefore, an increase in electricity price would reduce the industrial demand for electricity not only because quantity demanded and price are negatively related, but also because a higher price would make industries more responsive to the increase in price. A high-price policy to conserve energy is more effective in those industries which are more electricity-intensive in production or use electricity more as an indirect input than to those industries which are less electricity-intensive in production or use electricity more as a direct input.

In conclusion, it is worthwhile noting that the forecasts based on econometric models are conditional forecasts. Eventual realization of the forecast results depends to a great extent on the realization of the assumptions made for exogenous variables. As time passes, new sets of assumptions and, hence, new forecasts may be needed if the earlier assumptions prove unrealistic. The availability of additional data may also require updating of the equations. Consequently, econometric forecasting and analyses are continuous and long-run processes. The conclusion of this report should mark another milestone, not the completion, of the econometric study of the demand for electricity in manufacturing industries in the United States.

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22. For an explanation of this method, see Klein (ref. 21) pp. 238-40.

23. These unpublished projections were obtained from Terry Morlan, Chief of the Demand Analysis Division, Energy Information Administration. The projections are not released at the state level as EIA forecasts, but are consistent with the regional forecasts used for the 1978 Annual Report to Congress, Series C.

24. The DRI projections as used by the Energy Information Administration in its *Annual Report to Congress 1977* are 6.0% for 1976-80, 5.0% for 1980-85, and 4.1% for 1985-90.

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30. The results obtained from ordinary least squares with the same variables are as follows:

$$SPE_i = \underset{(-0.04)}{-0.596} + \underset{(0.42)}{0.00001} \frac{E_i}{V_i} + \underset{(1.99)}{0.0008}\, PE_i - \underset{(-2.32)}{1.207}\, SEV_i$$

$$+ \underset{(2.96)}{1.418}\, \lambda_i$$

$$R^2 = 0.56$$

31. The results obtained from ordinary least squares are as follows:

$$LPE_i = \underset{(0.25)}{0.212} + \underset{(0.29)}{0.00001} \frac{E_i}{V_i} + \underset{(2.05)}{0.001} PE_i - \underset{(-1.89)}{1.446} SEV_i ,$$

$R^2 = 0.43$.

Appendix A

DEFINITION OF VARIABLES AND DATA SOURCES

Table A. Definition of variables used in the econometric models

Description of variable	Unit of measurement	Symbol: Individual industry	Symbol: All industry	Data sources[a]
Electricity purchased and generated	10^6 kWh	E		1,2,3
Average price of electricity	Cents/10^3 kWh	PE		1,2,3
Average price of natural gas	Dollars/10^3 therms	PG		4,5
Wholesale price index of coal	1967 = 100		PC	6,7,8
Average price of heavy fuel oil	Cents/gallon		PO	9
Value added	10^6 dollars	V		2,10,11
Average maintenance costs	Cents kWh		K	12
Ratio of industrial sales to total sales of electricity	Percent		RE	12
Wholesale price index of intermediate materials, supplies, and components	1967 = 100		WPI	6,7,8
Wholesale price index of industrial output	1967 = 100		WPM	6,7,8
Dummy variable	= 0: 1959–1973 = 1: 1974–1977		D	

[a]See the following footnotes for this table.

Footnotes for Table A: Data Sources

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Appendix B

REGRESSION RESULTS BY ORDINARY LEAST SQUARES AND TWO-STAGE LEAST SQUARES

Table B.1. Industrial demand equations estimated by ordinary least squares (OLS) and two-stage least squares (2SLS)[a]

(the dependent variable = ℓn E)

Industry SIC code	Estimation method	Constant (α_0)	$\ell n E_{-1}$ (α_1)	ℓn PE/WPI (α_2)	ℓn PG/WPI (α_3)	ℓn PC/WPI (α_4)	ℓn PO/WPI (α_5)	ℓn V/WPM (α_6)	T (α_7)	ℓn W/WPI (α_8)	D (α_9)	D-W	R^2
203	OLS	7.367	0.395	-1.587	0.432		1.038	0.304			-0.405	2.130	0.995
		(3.71)	(0.11)	(0.24)	(0.14)		(0.52)	(0.09)			(0.20)		
	2SLS	5.949	0.452	-1.446	0.388		1.055	0.311			-0.410		
		(4.24)	(0.13)	(0.31)	(0.15)		(0.53)	(0.10)			(0.20)		
204	OLS	0.466	0.847	-0.235			0.370	0.107			-0.136	2.968	0.989
		(2.06)	(0.12)	(0.23)			(0.45)	(0.05)			(0.17)		
	2SLS	0.701	0.818	-0.296			0.451	0.116			-0.161		
		(2.21)	(0.16)	(0.31)			(0.53)	(0.06)			(0.19)		
221	OLS	2.548	0.209	-0.178			0.461	0.476			-0.179	2.397	0.994
		(0.89)	(0.08)	(0.10)			(0.16)	(0.04)			(0.05)		
	2SLS	2.157	0.243	-0.105			0.385	0.470			-0.163		
		(0.95)	(0.08)	(0.11)			(0.17)	(0.04)			(0.06)		
225	OLS	3.500	0.456	-1.039	0.443		0.641	0.470	-0.049		-0.295	2.762	0.997
		(2.77)	(0.09)	(0.17)	(0.14)		(0.47)	(0.16)	(0.04)		(0.19)		
	2SLS	3.212	0.461	-1.001	0.438		0.622	0.483	-0.051		-0.289		
		(3.69)	(0.10)	(0.36)	(0.15)		(0.50)	(0.20)	(0.04)		(0.19)		
262	OLS	8.717	0.303	-0.827	0.462	0.063		0.237	0.037		-0.059	2.756	0.996
		(2.58)	(0.15)	(0.19)	(0.07)	(0.05)		(0.10)	(0.02)		(0.03)		
	2SLS	9.105	0.287	-0.857	0.471	0.067		0.228	0.039		-0.056		
		(3.43)	(0.17)	(0.26)	(0.09)	(0.06)		(0.12)	(0.03)		(0.03)		

Table B.1 (continued)

Industry SIC code	Estimation method	Constant (α_0)	$\ell n E_{-1}$ (α_1)	ℓn PE/WPI (α_2)	ℓn PG/WPI (α_3)	ℓn PC/WPI (α_4)	ℓn PO/WPI (α_5)	ℓn V/WPM (α_6)	T (α_7)	ℓn W/WPI (α_8)	D (α_9)	D-W	R^2
263	OLS	3.278	0.128	-0.189	0.178	0.111		0.716			0.012	2.542	0.994
		(2.30)	(0.12)	(0.22)	(0.09)	(0.05)		(0.13)			(0.04)		
	2SLS	3.625	0.121	-0.222	0.187	0.112		0.704			0.015		
		(3.38)	(0.13)	(0.32)	(0.11)	(0.05)		(0.16)			(0.04)		
282	OLS	3.531	0.594	-0.635	0.372	0.118		0.325			-0.012	2.823	0.996
		(1.82)	(0.08)	(0.23)	(0.11)	(0.07)		(0.09)			(0.05)		
	2SLS	3.005	0.603	-0.565	0.350	0.112		0.335			-0.018		
		(2.40)	(0.09)	(0.31)	(0.13)	(0.07)		(0.10)			(0.05)		
281A	OLS	5.624	0.480	-0.520				0.395			0.090	1.790	0.962
		(1.08)	(0.11)	(0.12)				(0.10)			(0.06)		
	2SLS	3.672	0.472	-0.232				0.412			0.056		
		(1.69)	(0.13)	(0.22)				(0.12)			(0.08)		
291	OLS	0.761	0.820	-0.058				0.176			0.044	2.215	0.996
		(1.12)	(0.05)	(0.11)				(0.05)			(0.03)		
	2SLS	0.388	0.829	-0.020				0.180			0.037		
		(1.18)	(0.05)	(0.12)				(0.05)			(0.03)		
322	OLS	8.452	0.110	-0.870	0.248	0.126		0.322		0.767	0.038	2.283	0.999
		(1.64)	(0.12)	(0.151)	(0.10)	(0.06)		(0.14)		(0.16)	(0.03)		
	2SLS	9.976	0.158	-1.060	0.301	0.110		0.219		0.754	0.051		
		(3.03)	(0.15)	(0.35)	(0.13)	(0.06)		(0.22)		(0.17)	(0.04)		
324	OLS	0.947	0.256	-0.071	0.185			0.825	0.063		0.049	1.972	0.966
		(3.11)	(0.18)	(0.20)	(0.08)			(0.18)	(0.02)		(0.04)		
	2SLS	0.658	0.265	-0.050	0.182			0.834	0.064		0.046		
		(3.24)	(0.18)	(0.21)	(0.08)			(0.18)	(0.02)		(0.04)		

Table B.1 (continued)

Industry SIC code	Estimation method	Constant (α_0)	$\ln E_{-1}$ (α_1)	$\ln$ PE/WPI (α_2)	$\ln$ PG/WPI (α_3)	$\ln$ PC/WPI (α_4)	$\ln$ PO/WPI (α_5)	$\ln$ V/WPM (α_6)	T (α_7)	$\ln$ W/WPI (α_8)	D (α_9)	D-W	R^2
331	OLS	1.342	0.532	-0.464	0.560	0.250		0.392			-0.088	2.759	0.986
		(2.24)	(0.08)	(0.21)	(0.12)	(0.06)		(0.09)			(0.04)		
	2SLS	1.189	0.535	-0.449	0.556	0.248		0.395			-0.089		
		(2.50)	(0.08)	(0.23)	(0.13)	(0.06)		(0.10)			(0.04)		
332	OLS	-3.432	1.020	-0.167	0.355			0.434			-0.119	1.764	0.988
		(5.26)	(0.15)	(0.57)	(0.28)			(0.20)			(0.08)		
	2SLS	-0.867	0.972	-0.462	0.465			0.373			-0.109		
		(6.17)	(0.16)	(0.68)	(0.31)			(0.21)			(0.08)		
333	OLS	3.066	0.315	-0.333		0.314		0.683			0.030	2.334	0.967
		(2.17)	(0.12)	(0.28)		(0.10)		(0.16)			(0.06)		
	2SLS	4.012	0.321	-0.461		0.300		0.658			0.050		
		(2.65)	(0.13)	(0.35)		(0.10)		(0.17)			(0.07)		
371	OLS	10.423	0.131	-1.327	0.655			0.469			0.028	1.651	0.982
		(2.24)	(0.10)	(0.26)	(0.15)			(0.09)			(0.06)		
	2SLS	11.873	0.095	-1.505	0.714			0.459			0.042		
		(3.89)	(0.13)	(0.47)	(0.20)			(0.09)			(0.07)		

[a]Figures in parentheses are estimated standard errors. D-W is the Durbin-Watson statistic.

Table B.2. Industrial price equations estimated by ordinary least squares (OLS) and two-stage least squares (2SLS)[a]

(the dependent variable = PE - K)

Industry SIC code	Estimation method	Constant (β_0)	E (β_1)	RE (β_2)	D (β_3)	D-W	R^2
203	OLS	594	-0.103	-1358	-259	2.025	0.957
		(542.13)	(0.03)	(1029.79)	(30.13)		
	2SLS	808	-0.114	-1760	-258		
		(824.26)	(0.04)	(1554.44)	(30.42)		
204	OLS	1774	-0.127	-3456	-279	1.232	0.895
		(880.52)	(0.05)	(1479.84)	(37.53)		
	2SLS	1927	-0.135	-3710	-277		
		(953.25)	(0.05)	(1598.78)	(37.70)		
221	OLS	-54	0.032	-2142	-118	1.883	0.853
		(111.89)	(0.01)	(253.62)	(29.34)		
	2SLS	-59	0.034	-2154	-116		
		(112.10)	(0.01)	(254.18)	(29.48)		
225	OLS	920	-0.127	-2306	-252	2.012	0.897
		(491.28)	(0.03)	(985.27)	(48.18)		
	2SLS	508	-0.101	-1504	-260		
		(536.05)	(0.03)	(1701.79)	(49.76)		
262	OLS	285	-0.009	-2007	-374	1.527	0.888
		(691.76)	(0.01)	(1161.86)	(38.79)		
	2SLS	226	-0.008	-1911	-374		
		(715.74)	(0.01)	(1200.06)	(38.80)		
263	OLS	-918	-0.002	384	-390	1.839	0.911
		(684.89)	(0.01)	(1197.78)	(43.52)		
	2SLS	-1019	-0.0001	555	-392		
		(710.28)	(0.01)	(1239.87)	(43.63)		
282	OLS	-56	-0.006	-1507	-282	1.423	0.864
		(512.14)	(0.01)	(970.33)	(32.83)		
	2SLS	-108	-0.006	-1410	-283		
		(531.56)	(0.01)	(1005.87)	(32.86)		
281A	OLS	3026	-0.014	-6822	-398	1.498	0.780
		(1054.41)	(0.004)	(1759.35)	(73.87)		
	2SLS	3510	-0.017	-7597	-389		
		(1743.14)	(0.01)	(2832.26)	(78.63)		
291	OLS	-633	0.0003	-494	-381	1.490	0.905
		(814.00)	(0.01)	(1408.72)	(37.31)		
	2SLS	-703	0.001	-373	-382		
		(893.76)	(0.01)	(1542.92)	(37.42)		

Table B.2 (continued)

Industry SIC code	Estimation method	Constant (β_0)	E (β_1)	RE (β_2)	D (β_3)	D-W	R^2
322	OLS	460	-0.031	-2319	-170	1.396	0.709
		(536.93)	(0.03)	(988.47)	(40.61)		
	2SLS	353	-0.025	-2126	-175		
		(545.48)	(0.03)	(1003.61)	(40.85)		
324	OLS	-193	-0.005	-1055	-248	0.899	0.831
		(446.53)	(0.02)	(625.11)	(30.72)		
	2SLS	-211	-0.004	-1033	-248		
		(462.97)	(0.02)	(644.44)	(30.75)		
331	OLS	-595	0.002	-629	-273	2.308	0.934
		(277.945)	(0.001)	(465.67)	(20.68)		
	2SLS	-711	0.003	-445	-271		
		(292.81)	(0.002)	(488.58)	(20.87)		
332	OLS	-310	-0.002	-134	-186	1.109	0.913
		(263.45)	(0.01)	(496.42)	(23.38)		
	2SLS	-316	-0.002	-123	-186		
		(271.60)	(0.01)	(511.06)	(23.66)		
333	OLS	-2174	0.007	1288	-748	1.510	0.920
		(777.86)	(0.003)	(1355.012)	(65.293)		
	2SLS	-2260	0.008	1430	-749		
		(805.42)	(0.004)	(1398.09)	(65.38)		
371	OLS	605	-0.010	-2174	-61	1.992	0.633
		(388.85)	(0.01)	(674.67)	(28.79)		
	2SLS	613	0.001	-1143	-46		
		(482.88)	(0.01)	(830.99)	(32.06)		

[a]Figures in parentheses are estimated standard errors. D-W is the Durbin-Watson statistic.

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