

A DYNAMIC AND STATIC STUDY OF CAPITAL, LABOUR, AND ENERGY
SUBSTITUTABILITY: Eleven Canadian Industrial Sectors

by

Kevin Francis Campbell
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We accept this thesis as conforming
to the required standard

Dr. K. G. Stewart, Supervisor (Department of Economics)

Dr. D. Ferguson, Departmental Member (Department of Economics)

Dr. M. Lesperance, Outside Member (Department of Mathematics)

Dr. Zheng Wu, External Examiner (Department of Sociology)

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University of Victoria

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Supervisor: Dr. Ken G. Stewart

ABSTRACT

Recent studies on factor substitution have concentrated on the use of flexible functional forms such as the translog cost function. These functions allow the elasticities of substitution to assume arbitrary but theoretically consistent values. By theoretically consistent I mean that the cost function is capable of taking on all the desirable properties of a cost function. I make use of the translog function first to estimate an energy submodel, which consists of gasoline, fuel oil, electricity, coal and coke, natural gas, and liquid petroleum gas. This is used to derive a price index for energy which along with price series for labour and capital for eleven Canadian industrial sectors, is used in a dynamic and a static study of capital, labour, energy (KLE) substitutability. By substitutability I mean the degree to which the producer is able to replace one factor of production with another as their relative prices change.

In both studies tests are performed to determine whether the model has Hicks neutral technological change, homotheticity, homogeneity, homogeneity and symmetry and whether the underlying cost function is concave. To test for the concavity of the cost function the characteristic roots are examined, for the other properties a likelihood ratio test

is performed. Furthermore the static, partial adjustment, and autoregressive models are nested within the dynamic model, so tests are performed to determine the correct structure of the model. Once this has been accomplished both the Allen elasticities of substitution and the price elasticities of substitution are derived. This is done for the energy submodel, the static model, and the dynamic model.

Examiners:


Dr. K. G. Stewart, Supervisor (Department of Economics)


Dr. D. Ferguson, Departmental Member (Department of Economics)


Dr. M. Lesperance, Outside Member (Department of Mathematics)



Dr. Zheng Wu, External Examiner (Department of Sociology)

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CHAPTER 1 INTRODUCTION

The purpose of this dissertation is to estimate a capital, labour, and energy production model for eleven Canadian industrial sectors using a time series sample from 1963 to 1984. This is to be accomplished in a two step procedure. First an energy aggregate with an associated price index is estimated by assuming the price for energy can be derived as an explicit function of six types of energy.¹ These types of energy are gasoline, fuel oil, electricity, coal and coke, natural gas, and liquid petroleum gas. Thus the price of energy is assumed to be endogenous because it is derived from the energy types but the price of the various components are exogenous. Second the derived price for energy is used along with price series for capital and labour to estimate both a static model and a dynamic model of input share equations. In the static model it is assumed that the firm is able to adjust instantaneously to such things as a change in relative prices. In the dynamic model it is assumed that adjustment costs, the formation of expectations, and the misinterpretation of real price changes may prevent the firm from adjusting instantaneously.

In the energy submodel in order to derive the aggregate price for energy it was necessary to assume homogeneity and symmetry, Hicks neutral technological change (HNTC) and

¹ As we shall see this is done by assuming that energy is weakly separable from the other inputs.

homotheticity.² Here a static model was assumed and no tests were performed on the structure of the model. However in the static and dynamic KLE model homogeneity, symmetry, HNTC, and homotheticity are tested for using a likelihood ratio test. This test is based on the idea that if the hypothesized restrictions are true the value of the likelihood function with the restrictions cannot be much different from the likelihood function without the restrictions.³ The test statistic is given by:

$$LR = -2[L(R) - L(UR)] \sim \chi^2_n$$

where $L(R)$ is the likelihood function with the restrictions imposed, $L(UR)$ is that function without the restrictions imposed and n is the number of restrictions.

The features are tested because according to economic theory the input demand shares must be homogeneous and symmetric, also it is considered important to identify the nature of technological change and homotheticity because it helps to identify the nature of the cost structure. For example if we are interested in whether the technology evolves over time then we test for Hicks neutral technological change.

The same test is first used to identify the correct dynamic structure of the model be it autoregressive, partial adjustment, static or dynamic. This is so because the

² For a definition of homotheticity see below. Hicks neutral technological change means that for all factor prices held constant technological change affects all factors equiproportionately.

³ Kmenta Elements of Econometrics p 491.

autoregressive and partial adjustment models are nested within the dynamic model, and the static model is nested within the partial adjustment and autoregressive models.

Once the correct structure of the model is known the Allen elasticities of substitution (AES) and the price elasticities of substitution are derived. In the energy submodel these are used to examine the degree of interfuel substitution. In both the static and dynamic models the AES and price elasticities are used to examine the degree of substitutability among the capital, labour, and energy inputs. Both are considered to be of important policy implications. Take for example the implication of a significant rise in the price of fuel oil. If the firm is able to easily substitute another energy type for oil then the increase in cost may not prove to be inflationary. If on the other hand the firm is constrained by the other types of fuel being substitutes then the increase in the price of oil will be passed onto the consumer. Furthermore it is considerable interest to know whether or not capital and labour are complements or substitutes. If the government is consider lowering the corporate income tax rate then whether or not there will be a decrease or increase in the firm's usage of labour depends on if they are substitutes or complements. This study is considered to be important for two other reasons. First, as we shall see there is quite a debate over the AES's for various factors, and it is hoped that this paper can

contribute something to that debate. Second, a dynamic model is presented and tested against the static, partial adjustment, and autoregressive: each of these models indicate the ability of the firm to adjust over time. If they are able to adjust quickly over time then for things such as tax changes, accelerated depreciation allowances, investment tax credits, and fixed wages settlements the lag between implementation and adjustment by the firm will be small.

The rest of this paper is organized as follows. Chapter 2 is a review of the theory of cost and production. Chapter 3 is a literature review. Chapter 4 is an estimation of the energy submodel. In chapter 5 I present the static KLE model, while chapter 6 is a presentation of the dynamic KLE model. Finally chapter 7 concludes.

CHAPTER 2 COST AND PRODUCTION

2.1 The Theory of Cost and Production

2.1.1 Input Substitution and the Production Function

In this paper we are concerned with the theory of production and cost to the extent that it allows us to derive an estimable energy submodel and a capital, labour, and energy factor share model. To this end we present a brief introduction of the theory of cost and production.

In studying input substitution patterns among capital, labour, and energy certain assumptions are made about the extent to which the inputs are substitutable for one another. Typically the starting point is to assume a production function which relates the inputs to the maximum attainable output. It is denoted by:

$$Q = f(X) \qquad 2.1$$

where Q is output and X is a vector of inputs denoted (x_1, x_2, \dots, x_n) . The production function is assumed to be real valued, nondecreasing in the inputs, continuous, and quasiconcave.

2.1.2 The Profit Function

This production function is used in one of two optimization problems, profit maximization or cost minimization. The profit maximization problem stated simply is:

$$\max_{\mathbf{x}} \pi(\mathbf{x}, \rho, \mathbf{p}) = \rho f(\mathbf{X}) - \sum_{i=1}^n p_i x_i \quad 2.2$$

where ρ is the price of output, the p_i 's are the input prices, and \mathbf{X} is a vector of factor inputs denoted (x_1, \dots, x_n) . The solutions to this problem are the profit function $\pi(\rho, \mathbf{p})$ and the unconditional input demands $x_i^*(\rho, \mathbf{p})$. The input demands are said to be unconditional because they are not dependent on the level of the firm's output.

The profit function has the following four properties⁴:

1) is nondecreasing in ρ , $\frac{\partial \pi(\rho, \mathbf{p})}{\partial \rho} \geq 0$, and nonincreasing in

\mathbf{p} , $\frac{\partial \pi(\rho, \mathbf{p})}{\partial p} \leq 0$.

2) homogeneous of degree 1 in (ρ, \mathbf{p}) ,
 $\pi(t\rho, t\mathbf{p}) = t\pi(\rho, \mathbf{p}) \quad \forall t > 0$.

3) convex in (ρ, \mathbf{p}) .

4) continuous in (ρ, \mathbf{p}) .

2.1.3 The Cost Function

Rather than dealing directly with the profit function and the associated production function most studies choose to introduce its dual, the cost function. This function is found from the solution to the cost minimization problem given as:

⁴ Varian, Microeconomic Analysis p. 46.

$$\min_x \sum_i p_i x_i$$

Subject To $Q = f(X)$

2.3

where p_i is the price of the i^{th} input and the x_i 's are the factors of production. The cost minimizing inputs can be written as $x_i^*(p_1, \dots, p_n, Q)$ and the minimal value of the cost function is given as $C(p_1, \dots, p_n, Q) = p_1 x_1^*(p_1, \dots, p_n, Q) + \dots + p_n x_n^*(p_1, \dots, p_n, Q)$. There is a duality between the cost and the production functions. Duality stated simply says that for any cost function one can derive a unique production function which in turn can be used to derive the original cost function.

For any functional form to be a candidate for a cost function it must be theoretically consistent. This means that the function must be capable of possessing all the desirable properties of a cost function.⁵

The cost function is defined to be theoretically consistent if it has the following four qualities.⁶ If the cost function possesses these properties over the whole range of input prices then it is said to be globally theoretically consistent, if it exhibits these properties for some local subset of input prices then it is said to be locally

⁵ Lawerance Lau "Functional Forms and Econometric Model Building", in The Handbook of Econometrics Volume 3 p. 1520.

⁶ *ibid.*, pp. 1522-1524.

consistent.⁷ The four properties are:

1) be nondecreasing in input prices with

$$x_1^*(p_1, \dots, p_n, Q) = \frac{\partial C(p_1, \dots, p_n, Q)}{\partial p_1} \quad 2.4$$

2) be homogeneous of degree one in input prices:

$$C(tp_1, \dots, tp_n, Q) = tC(p_1, \dots, p_n, Q) \quad 2.5$$

3) have input demands that are homogeneous of degree zero in input prices:

$$x_1^*(tp_1, \dots, tp_n, Q) = x_1(p_1, \dots, p_n, Q) \quad 2.6$$

4) be concave in the input prices.

The first property states that the effect of an increase in factor price on cost depends on how much of the input is being used. This result is known as Shephard's lemma.⁸ The second property states that an equiproportionate increase in the prices of all commodities will increase costs by the same proportionate amount.⁹ The third property states the absence of money illusion. If all input prices change equiproportionately, then the cost minimizing bundle will remain as before.¹⁰ The final property implies that the Hessian of the cost function be negative semidefinite. This

⁷ *ibid.*, p. 1527.

⁸ Varian Microeconomic Analysis p. 54.

⁹ Varian, Microeconomic Analysis pp. 6-49.

¹⁰ *ibid.* pp 6-49.

assures that function is at a global minimum. Among other things it also implies that the diagonal elements must be nonpositive and since by Shephard's lemma $\frac{\partial C}{\partial p_i} = x_i^*(p_1, \dots, p_n, Q)$,

which are the conditional input demand functions (conditional on the level of output). It follows that

$$\frac{\partial^2 C(p_1, \dots, p_n, Q)}{\partial p_i^2} = \frac{\partial x_i^*(p_1, \dots, p_n, Q)}{\partial p_i} \leq 0. \text{ In other words the}$$

input demand functions are nondecreasing in their own prices. One advantage of using the cost function instead of the associated production function is that it allows us to directly derive the Allen elasticities of substitution. These are a measure of how the ratios of factor usages change in response to changes in factor prices and are given by:

$$\sigma_{ij} = \frac{C C_{ij}}{C_i C_j} \quad 2.7$$

where

$$C_i = \frac{\partial C}{\partial p_i} \text{ and } C_{ij} = \frac{\partial^2 C}{\partial p_i \partial p_j} \quad 2.8$$

If the AES's are positive then the two factors are said to be substitutes, if they are negative then the factors are complements. These elasticities are related to the price elasticities of demand in the following way:

$$E_{ij} = S_j \sigma_{ij} \quad 2.9$$

where S_j is the factor share of the j^{th} input. And the factor shares are derived from the data in the following way:

$$S_j = \frac{p_j x_j^*(p, Q)}{\sum_{i=1}^n p_i x_i^*(p, Q)} \quad 2.10$$

where $x_i^*(p, Q)$'s are the solutions to the cost minimizing problem. These price elasticities show how a change in the price of one factor influences the demand for another factor. One can see that although the $\sigma_{ij} = \sigma_{ji}$ in general E_{ij} is not equal to E_{ji} .

2.1.4 Flexible Functional Forms

In recent years many flexible functional forms have been introduced as candidates for cost functions in the applied economic literature. A function is said to be flexible if and only if it is capable of generating input demands whose price elasticities can assume arbitrary values, subject to being theoretical consistent through an appropriate choice of parameters.¹¹

One of these functions that has gained wide currency in the literature is the transcendental logarithmic cost function

¹¹ Lawerance Lau "Functional Forms and Econometric Model Building", in The Handbook of Econometrics Volume 3 p. 1529.

(or translog for short) introduced by Christensen, Jorgenson, and Lau.¹² A homothetic version of the cost function is given as:

$$\begin{aligned} \ln C(p_1, \dots, p_n, Q) &= \ln \alpha_0 + \ln Q + \sum_{i=1}^n \alpha_i \ln p_i \\ &+ \frac{1}{2} \sum_{i=1}^n \sum_{j=1}^n \beta_{ij} \ln p_i \ln p_j \end{aligned} \quad 2.11$$

The translog cost function is a second order approximation to any cost function.

A major advantage of the translog cost function is that it has share equations that are linear in their parameters, specifically:

$$\begin{aligned} \frac{\partial \ln C}{\partial \ln p_i} &= \frac{\partial C}{\partial p_i} \frac{p_i}{C} = \frac{x_i p_i}{C} \\ &= \alpha_i + \sum_j \beta_{ij} \ln p_j = S_i \end{aligned} \quad 2.12$$

where $C = \sum_{i=1}^n p_i x_i^*(p, Q)$. And the β_{ii} 's indicate the own price

effects and the β_{ij} 's indicate the cross price effects. These indicate what happens to the share of a given input if its or

¹² Christensen, L.R., Jorgenson D.W., and Lau L.J., "Transcendental Logarithmic Production Frontiers." Review of Economics and Statistics pp. 28-45.

another factor price changes.

The AES for the translog cost function are given as:

$$\sigma_{ii} = \frac{\beta_{ii} + S_i^2 - S_i}{S_i^2} \quad 2.13$$

$$\sigma_{ij} = \frac{\beta_{ij} + S_i S_j}{S_i S_j} \quad 2.14$$

Before proceeding with a review of the current literature using flexible functional forms I make a necessary divergence to discuss some preliminary definitions.

Throughout this paper I make use of a series of key terms and definitions. These are needed to summarize the literature as well as to test various hypothesis on the time series sample of eleven Canadian industrial sectors.

2.2 Separability and Homotheticity

2.2.1 Homotheticity

A production function is said to be homothetic if it is a positive monotonic transformation of a homogeneous function. More formally if $g(x)$ is homogeneous and $f(x)$ can be expressed as $H(g(x))$ where $H' > 0$, then $f(x)$ is homothetic.¹³ If $F(x)$ is homothetic then the cost function derived from the cost

¹³ Varain Microeconomic Analysis p. 76.

minimization problem can be written as:¹⁴

$$C(p_1, \dots, p_n, Q) = A(p_1, \dots, p_n)h(Q). \quad 2.15$$

Where $h(Q)$ is a monotonically increasing function of Q .

2.2.2 Separability

Consider a production function $Q = f(X) = f(x_1, x_2, \dots, x_n)$, now partition the factors into r mutually exclusive and exhaustive subsets $[N_1, \dots, N_r]$ call this partition R . The production function $f(X)$ is said to be strongly separable if and only if:

$$\frac{\partial}{\partial x_k} \left(\frac{f_i}{f_j} \right) = 0 \quad i \in N_s, j \in N_t, k \notin N_s \cup N_t \quad 2.16$$

where the F_i 's are the partial derivatives of $f(X)$ with respect to the x_i 's.¹⁵

The production function is homothetically weakly separable with respect to the partition R if the marginal rate of substitution between any two inputs x_i and x_j from any subset N_m , $m = 1, 2, \dots, r$ is independent of output and the quantities of inputs external to N_m , i.e.¹⁶

$$\frac{\partial}{\partial x_k} \left(\frac{f_i}{f_j} \right) = 0, \quad i, j \in N_m, k \notin N_m \quad 2.17$$

¹⁴ Varian Microeconomic Analysis p. 337.

¹⁵ Blackorby, C., Primont, D., Russell, R., "On Testing Separability Restrictions With Flexible Functional Forms." Journal of Econometrics 1977 p 197.

¹⁶ *ibid.* p 197.

This is necessary and sufficient for the production function to be of the form $F^*(x_1', \dots, x_r')$ where x_i' is a positive strictly quasiconcave homothetic production subfunction i.e.

$$x_i' = f(x_i), \quad i \in N_i, \quad i = 1, 2, \dots, n \quad 2.18$$

If the production function is homothetically weakly separable in the partition R then the corresponding cost function has the same partition in input prices, that is:

$$C = C(p_1', \dots, p_m', Q) \quad 2.19$$

Where the input prices are positive strictly quasi-concave homothetic functions of any elements in N_m i.e.

$$p_m' = g_m(p_i), \quad i \in N_m, \quad m = 1, 2, \dots, r \quad 2.20$$

In what follows I shall present a review of the current literature on input substitutability using flexible functional forms for capital, K, labour, L, energy, E, and in some cases materials, M (KLEM). These studies include Griffon and Gregory's study using pooled data from nine OECD industrialized countries; Fuss's pooled data for Canadian manufacturing; the Berndt and Wood study for United States manufacturing; Anderson and Blundell's study for the American industrial sector; and Friesen who extends the United States data set of Berndt and Wood. All of these studies with the exception of Friesen and Anderson and Blundell are static in nature which is to say it is assumed that firms are able to optimize their input decisions instantaneously.

CHAPTER 3 LITERATURE REVIEW

3.1 The Berndt and Wood Study

I present Berndt and Wood's time series study first because it began the capital energy substitute/complement debate. As we shall see the authors find energy and capital to be substantial complements, whereas other studies find them to be substitutes.

In a study on the demand for energy Berndt and Wood note that the demand for energy is essentially a derived demand: the firm's demand for energy as an input is derived from the demand for the firm's output.¹⁷ Since the firms act as cost minimizers the derived demand for inputs depends on the level of output, the substitution possibilities allowed by the technology and the relative prices of each input.¹⁸

The authors note that previous studies have either focused solely on the level of output as the determining factor for the demand for energy, the accelerator theories; or on neoclassical studies which focuses on output and the prices of capital, labour, and energy. At the time of writing the article, Berndt and Wood were unable to name a study which explicitly investigated cross-substitution possibilities between energy and nonenergy inputs.

¹⁷ Ernst R. Berndt and David O. Wood "Technology, Prices, and the Derived Demand for Energy." In The Review of Economics and Statistics p.259.

¹⁸ ibid. p. 259.

The degree of substitution between energy and non energy input substitution has important policy implications. Suppose for example that there is a rise in the price of energy, what is the effect on capital investment? If energy and capital are substitutes, then the higher price for energy will increase the demand for capital, if they are complements, then it will reduce the demand for capital services. Whether capital and energy are complements or substitutes has important policy implications which have to be taken into account when the government is considering such things as an investment tax credit, accelerated depreciation allowances, or changing the marginal rates of taxation.

3.1.1 The Assumed Technology

To examine the level of substitution between capital, labour, energy, and materials Berndt and Wood assume that there exists for the United States a twice differentiable aggregate production function Q relating the maximum attainable output to the inputs K (capital), L (labour), E (energy), and M (materials). Under duality there exists a corresponding cost function:

$$C = C(p_K, p_L, p_E, p_M, Q) \quad 3.1$$

Their choice for a cost function is the translog which is given as:

$$\begin{aligned} \ln C = & \ln \alpha_0 + \ln Q + \alpha_K \ln p_K + \alpha_L \ln p_L + \alpha_E \ln p_E + \alpha_M \ln p_M \\ & + 1/2 \gamma_{KK} (\ln p_K)^2 + \gamma_{KL} \ln p_K \ln p_L + \gamma_{KE} \ln p_K \ln p_E + \gamma_{KM} \ln p_K \ln p_M \end{aligned}$$

$$\begin{aligned}
& + 1/2\gamma_{LL}(\ln p)^2 + \gamma_{LE}\ln p_L \ln p_E + \gamma_{LM}\ln p_L \ln p_M + 1/2\gamma_{EE}(\ln p_E)^2 \\
& + \gamma_{EM}\ln p_E \ln p_M + 1/2\gamma_{MM}(\ln p_M)^2
\end{aligned} \tag{3.2}$$

The following restrictions must hold for linear homogeneity and symmetry:

$$\begin{aligned}
\gamma_{ij} &= \gamma_{ji} \\
\alpha_K + \alpha_L + \alpha_E + \alpha_M &= 1 \\
\gamma_{KK} + \gamma_{KL} + \gamma_{KE} + \gamma_{KM} &= 0 \\
\gamma_{LL} + \gamma_{LE} + \gamma_{LM} + \gamma_{LK} &= 0 \\
\gamma_{EE} + \gamma_{EL} + \gamma_{EM} + \gamma_{EK} &= 0 \\
\gamma_{MM} + \gamma_{MK} + \gamma_{ML} + \gamma_{ME} &= 0
\end{aligned} \tag{3.3}$$

3.1.2 The Share Equations

The input demand shares are derived by logarithmic differentiation and an application of Shephard's lemma:

$$\frac{\partial \ln C}{\partial \ln p_1} = \frac{\partial C}{\partial p_1} \frac{p_1}{C} = \frac{x_1^* p_1}{C} = S_1 \tag{3.4}$$

These share equations are expressed as:

$$\begin{aligned}
S_K &= \alpha_K + \gamma_{KK}\ln p_K + \gamma_{KL}\ln p_L + \gamma_{KE}\ln p_E + \gamma_{KM}\ln p_M \\
S_L &= \alpha_L + \gamma_{KL}\ln p_K + \gamma_{LL}\ln p_L + \gamma_{LE}\ln p_E + \gamma_{LM}\ln p_M \\
S_E &= \alpha_E + \gamma_{KE}\ln p_K + \gamma_{LE}\ln p_L + \gamma_{EE}\ln p_E + \gamma_{EM}\ln p_M \\
S_M &= \alpha_M + \gamma_{KM}\ln p_K + \gamma_{LM}\ln p_L + \gamma_{EM}\ln p_E + \gamma_{MM}\ln p_M
\end{aligned} \tag{3.5}$$

Assuming that deviations in cost shares are the result of

random errors made in the cost minimizing behaviour the authors add to each share equation a random error term.¹⁹ Because the input shares by definition always sum to unity the sum of the disturbances across all four equations is zero at each observation.²⁰ This implies that the disturbance covariance matrix is singular and nondiagonal.²¹ In order to avoid this problem one equation is omitted from the econometric estimation.

Berndt and Wood apply iterative three stage least squares estimation, with linear homogeneity imposed on the prices, to data for U.S. manufacturing for the period 1947-1971. They find that energy and labour are slight substitutes with σ_{LE} equal to about .65; energy and capital display substantial complementary with σ_{KE} equal to -3.2; and they estimate σ_{KL} to be 1.01.

3.2 The Griffon and Gregory Study

I next examine the work of Griffon and Gregory who attempt to validate the time series results of Berndt and Wood. In their effort to examine the validity of the time series models of capital, labour, energy, and material substitution Griffon and Gregory present a study using pooled data for manufacturing for nine industrialized countries.

¹⁹ Ernst R. Berndt and David O. Wood "Technology, Prices and the Derived Demand for Energy." In The Review of Economics and Statistics p. 261.

²⁰ ibid. p. 261.

²¹ ibid. p. 261.

Typically the literature assumes negligible substitutability opportunities between energy and material vis-a-vis capital and labour inputs.²²

Using a capital, labour, energy, and materials study (KLEM) of US manufacturing for the time period 1947-71 Berndt and Wood find that energy is a substitute for labour and a complement for capital. These are short run results and it is plausible that capital and energy may in the long run be substitutes as higher efficiency machines take the place of energy using equipment.

To examine the validity of these findings Griffon and Gregory examine pooled international data for manufacturing. To circumvent the problems of limited price variation and the capturing of short run responses, they estimated a translog cost function from international data (1955-69) for the manufacturing sector of nine industrialized countries.²³

3.2.1 The Assumed Technology

The authors assume that for the manufacturing sector there exists a twice differentiable aggregate production function relating the maximum attainable output Q to the level of inputs K, L, E, M :

²² James M. Griffon and Paul R. Gregory. "An Intercountry Translog Model of Energy Substitution Responses." The American Economic Review p. 845.

²³ *ibid.* p. 845.

$$Q = f(K, L, E, M, t) \quad 3.6$$

where t is a time index. The dual of this function is the cost function which may be written as:

$$C = C(P_K, P_L, P_E, P_M, Q, t) \quad 3.7$$

The authors assume the existence of a homothetic aggregator consisting of capital, labour, and energy which is weakly separable from materials.²⁴ Thus 3.7 may be rewritten as:

$$C = C(C_1(P_K, P_L, P_E), P_M, Q, t) \quad 3.8$$

This aggregator function is written as:

$$\ln \phi = \ln \alpha_0 + \sum_{i=1}^n \alpha_i \ln p_i + 1/2 \sum_{i=1}^n \sum_{j=1}^n \beta \ln p_i \ln p_j \quad 3.9$$

Where $i, j = K, L, E$. This equation gives rise to three input demand shares, however the specification of any two completely determines the model because the system is singular. The authors use the following two equations:

$$S_K = \alpha_K + \beta_{KK} \ln p_K + \beta_{KL} \ln p_L - (\beta_{KK} + \beta_{KL}) \ln p_E \quad 3.10$$

$$S_L = \alpha_L + \beta_{KL} \ln p_K + \beta_{LL} \ln p_L - (\beta_{KL} + \beta_{LL}) \ln p_E \quad 3.11$$

These equations are used to derive the Allen elasticities of substitution and the price elasticities. The AES are as before. The own price elasticities are given as:

$$E_{ij} = S_j \sigma_{ij} \quad 3.12$$

²⁴ *ibid.*, p 848.

Empirically the authors find estimates of σ_{LE} that range from .72 in Denmark to .87 in Belgium and U.S. They also find σ_{KE} that range from 1.02 to 1.07 which means capital and energy are substitutes, these results contradict those obtained by Berndt-Wood who find them to be complements. The capital labour elasticities range from .39 to .52 but are not statistically different from zero. In addition to these results the own price elasticities were negative and in line with other studies.

3.3 The Fuss Study

In a Canadian study of energy substitutability and complementary, Fuss presents a two level model in which an aggregate energy price index is constructed from estimating a translog form of the six types of energy components. This index in turn is used in a second stage to estimate a KLEM model. This study is useful for two reasons: first, it contributes to the capital energy substitute/complement debate and second it offers a means for comparison for this capital, labour, energy (KLE) study.

3.3.1 The Assumed Technology

In the 1977 study Fuss examines the role different types of energy plays in a production process. Prior to this, most applied econometric work on input substitution has been concerned with the AES between the two factors of capital and labour using the constant elasticity of substitution production function. Fuss uses a flexible functional form.

This function allows for the use of many inputs but it is sometimes troubled with multicollinearity problems. In addition to these problems the function can be burdensome computationally. This problem is avoided by imposing a priori restrictions on the parameters, namely that the production function is weakly separable in labour, capital, energy, and materials.²⁵

Fuss assumes the following production function:

$$Q = f(E_1, \dots, E_n, L_1, \dots, L_n, K_1, \dots, K_n, M_1, \dots, M_n) \quad 3.13$$

which is further assumed to be weakly separable in KLEM i.e.:

$$Q = g(E(E_1, \dots, E_n), L(L_1, \dots, L_n), K(K_1, \dots, K_n), M(M_1, \dots, M_n)) \quad 3.14$$

By hypothesizing separability Fuss arrives at two simplifying results. First under weak separability an aggregator function exists. Second this implies a two stage optimization process: optimize the mix of components within each aggregate, then the level of each component. Fuss uses this fact to justify the construction of a submodel of energy components.

He starts with the second stage, the demand for aggregate inputs:

$$Q = f(K, L, E, M) \quad 3.15$$

Further assuming that duality holds he arrives at the cost function:

$$C = C(P_K, P_L, P_E, P_M, Q) \quad 3.16$$

²⁵ For a definition of weak separability see above.

where the notation is as before.

The following cost function is postulated:

$$\ln C = \ln \alpha_0 + \sum_i \ln p_i + \alpha_Q \ln Q + \sum_i \sum_j \gamma_{ij} \ln p_i \ln p_j + \sum_i \gamma_{iQ} \ln Q \ln p_i + 1/2 \gamma_{QQ} (\ln Q)^2 \quad 3.17$$

This function allows us to arrive at the following static input share system:

$$S_i = \alpha_i + \sum_i \gamma_{ij} \ln p_i + \gamma_{iQ} \ln Q \quad 3.18$$

The adding up restrictions and the tenets of neoclassical theory imply:

$$\sum_i \alpha_i = 1 \quad 3.19$$

$$\sum_i \gamma_{ij} = \sum_j \gamma_{ij} = 0 \quad 3.20$$

$$\sum_j \gamma_{iQ} = 0 \quad 3.21$$

$$\gamma_{ij} = \gamma_{ji} \quad 3.22$$

3.3.2 The Energy Submodel

The sub model consists of energy being an aggregate of six components. These are gasoline, fuel oil, electricity, coal and coke, natural gas, and liquid petroleum gas. It is assumed that the firm will choose the mix of energy types

which minimize the total cost of energy subject to the constraints imposed by the technology and the ability to substitute one energy type for another.²⁶ Thus the price of aggregate energy is assumed to be endogenous but the price of the underlying components is exogenous. This submodel is given as:

$$Q = f(E_1, \dots, E_n, L, K, M) \quad 3.23$$

now imposing homothetic weak separability we arrive at the following form of the production function:

$$Q = g(E(E_1, \dots, E_n), L, K, M) \quad 3.24$$

As we have already noted the corresponding cost function is also weakly separable:

$$C = C(P_E(P_{E_1}, \dots, P_{E_n}), P_L, P_M, P_K, Q) \quad 3.25$$

Where P_E is an aggregate price index. This is not a simple weighted average of all energy components unless all E_i 's are perfect substitutes or complements.

Fuss assumes that P_E can be represented in a translog form:

$$\ln p_E = \ln \beta_0 + \sum_i \beta_i \ln p_{E_i} + 1/2 \sum_i \sum_j \beta_{ij} \ln p_{E_i} \ln p_{E_j} \quad 3.26$$

This leads to the following input share system:

$$S_{E_i} = \beta_i + \sum_j \beta_{ij} \ln p_{E_j} \quad 3.27$$

²⁶ Melvyn Fuss "The Demand for Energy in Canadian Manufacturing: An Example of the Estimation of Production Structures with Many Inputs", Journal of Econometrics 1977.

Again the restrictions of neoclassical production theory imply:

$$\sum_i \beta_i = 1 \quad 3.28$$

$$\sum_i \beta_{ij} = \sum_j \beta_{ji} = 0 \quad 3.29$$

$$\beta_{ij} = \beta_{ji} \quad 3.30$$

Estimation of the submodel is now accomplished by the following two step procedure. First the system of 3.25 is estimated subject to the restrictions outlined above then the estimates of the β_i 's and the β_{ij} 's are used to obtain an index for the price of energy factors. Second we estimate 3.18 subject to the homogeneity and symmetry constraints using the fitted values of P_E .

3.3.3 The Empirical Results

Fuss estimates the following model using pooled time series data (1961-1971) and cross sectional data from four Canadian regions.

$$S_i = \alpha_i + \sum_j \gamma_{ij} \ln p_i + \gamma_{iQ} \ln Q + U_t \quad 3.31$$

where $j = K, L, E$ and

$$S_{Ei} = \beta_i + \sum_i \beta_{ij} \ln p_{Ei} + V_t \quad 3.32$$

where $i = 1, \dots, 6$. And U and V are vectors of random disturbances assumed to be identically independently

distributed.

At the level of the subfunction Fuss reports that all the own price elasticities are negative with the exception of motor gasoline, and that there appears to be a great deal of interfuel substitution.²⁷ For coal, liquid petroleum gas, fuel oil, and motor gasoline, the own price elasticities are less than -1 and the cross price elasticities are positive and in some cases substantially so.

At the aggregate level Fuss reports three results. First, of all the own price elasticities are negative and significantly different from zero. The AES's suggests that some complementary exists between energy and materials and energy and capital. This supports the Berndt and Wood study but not the Griffon Gregory study. Second, all aggregate factors have own price elasticities of demand which are in the inelastic range. In most cases they are less than .3 in absolute value. And finally the estimated capital labour elasticities are similar to those obtained by other studies.

3.4 The Anderson and Blundell Dynamic Study

So far I have considered static models: models in which it is assumed that the producer can adjust instantaneously to changes in such things as relative prices. If we consider adjustment costs, the formation of expectations, and the misinterpretation of real price changes then it may be more appropriate to try to use a dynamic specification of the input

²⁷ *ibid.* pp. 113-114.

share model in which firms take time to adjust to these changes. Anderson and Blundell accomplish this by including lagged endogenous and exogenous variables as regressors in the share equations.

They note that there have been many examples where empirical work rejects restrictions from economic theory such as homogeneity and symmetry. This is of great concern to theoretical economists who see fundamental postulates of economic theory being challenged. Anderson and Blundell believe the root of the problem is that little attention is being paid to the dynamic structure of the models being used.

3.4.1 The Model

They explore the possibility of estimating and testing models within a general dynamic specification of a singular demand system. This nonstochastic singular equilibrium input demand share system takes the form:

$$S(t) = f(x(t), \theta) \quad 3.33$$

which can be nonlinear. And where $S(t)$ is a $n \times 1$ vector of shares in total expenditure of factor classifications, and the vector function $f(\)$ depends upon $x(t)$ which are a series of deterministic variables which vary over time and a $J \times 1$ vector of parameters θ assumed constant over time. A linear version of this equation representing the translog technology may be written in a stochastic specification as:

$$S(t) = \Pi(\theta)x(t) + u(t) \quad 3.34$$

where $u(t)$ is a vector of identically independently

distributed error terms with mean 0 and constant variance and Π is a $n \times n$ matrix of parameters. If we assume that $x(t)$ takes the translog form the adding up restrictions imply:

$$i'\Pi(\theta) = (1, 0, 0, \dots, 0) \quad 3.35$$

$$i'u(t) = 0 \text{ for all } t \quad 3.36$$

Where i is the unit vector and the zeros represent the adding up restrictions for homogeneity while the one represents the restrictions for the intercept parameter. This represents a static model. A dynamic model may be written using a lag operator, L , to allow the firm to adjust to changes in such things as relative prices over time:²⁸

$$B(L)S(t) = \Gamma(L)x(t) + \varepsilon(t) \quad 3.37$$

where

$$B(L) = 1 + B_1L + B_2L^2 + \dots + B_pL^p \quad 3.38$$

$$\Gamma(L) = 1 + \Gamma_1L + \Gamma_2L^2 + \dots + \Gamma_qL^q \quad 3.39$$

where the B^1 's and Γ^1 's are the parameters to be estimated. Equation 3.37 can be reparameterized to give a set of equations of the form:²⁹

$$\Delta S(t) = -B(L)\Delta S(t) + \Gamma(L)\Delta x^*(t)$$

²⁸ G. J. Anderson and R. W. Blundell "Estimation and Hypothesis Testing in Dynamic Singular Demand Systems." Econometrica p. 1562.

²⁹ For a complete derivation of this see Anderson and Blundell "Estimation and Hypothesis Testing in Dynamic Singular Systems". Econometrica pp. 1563.

$$-B(1)(S(t-p) - B^*(1)^{-1}\Gamma(1)x(t-q)) + \epsilon(t) \quad 3.40$$

which can be expressed as:³⁰

$$\begin{aligned} \Delta S(t) = & -B(L)\Delta S(t) + \Gamma(L)\Delta x^*(t) \\ & - A(S(t-p) - \Pi(\Theta)x(t-q)) + \epsilon(t) \end{aligned} \quad 3.41$$

where Γ^* is Γ with the first column deleted and x^* is x with the first element deleted. The dynamic, partial adjustment, autoregressive, and static models can be derived from this equation.³¹ The restrictions that must hold in order for this to be true are given in Table 3.1 at the end of this chapter.

The dynamic model is given as:

$$\begin{aligned} \Delta S(t) = & \Gamma\Delta x^*(t) - A^n(S_n(t-1) - \\ & \Pi_n x(t-1)) + \epsilon(t) \end{aligned} \quad 3.42$$

The static model is represented by:

$$S(t) = \Pi x(t) + \epsilon(t) \quad 3.43$$

The static model with autoregressive errors is given by:

$$S(t) = \Pi x(t) + u(t) \quad 3.44$$

where

$$u(t) = R^n u(t-1) + \epsilon(t) \quad 3.45$$

Finally the partial adjustment model is given by:

$$\Delta S(t) = M(\Pi x(t) - S(t-1)) + \epsilon(t) \quad 3.46$$

Each of the autoregressive and partial adjustment models are

³⁰ *ibid.*, p. 1562.

³¹ *ibid.*, p. 1563.

nested within the dynamic model: the static model in turn is nested within the partial adjustment and autoregressive models.

These models were estimated with and without symmetry for annual time series data on U.S. manufacturing from 1929 to 1971. All of the symmetry restrictions were rejected. The autoregressive, partial adjustment, and static model are all rejected in favour of the dynamic model. Anderson and Blundell feel that the postulates of symmetry and homogeneity have not been validated because the likelihood ratio tests have all been rejected.

3.5 The Friesen Dynamic Study

Friesen extends the data set of Berndt and Wood, using annual American data from 1947 to 1991, and tests the dynamic structure of factor demands in the U.S. She argues that the current static models are misspecified and presents tests which appeal to the empirical data. To accomplish this she uses an alternative form of the dynamic model developed by Anderson and Blundell. She refers to this as the error correction model and it is essentially the Anderson Blundell model with the addition of more regressors.

This study is of interest for two reasons. First there are a number of studies using the Berndt Wood data set which employ a restricted cost function method. A number of these studies involve the energy-capital complement/substitute debate and the results of this study may shed new light on

this debate.³² Secondly the error correction model in and of itself may provide a useful alternative to the static models.

The advantage of the error correction model is that it allows the data to determine the dynamic specification of the cost structure. It accomplishes this because the autoregressive, partial adjustment, and static models are special cases of the error correction model.

Before proceeding to the empirical analysis there are two key assumptions that Friesen makes about the model. One, that there is a set of variable factors which are adjusted fully within a single period to their cost minimizing level, conditional of the levels of quasi-fixed factors. Two, the levels of quasi-fixed factors are predetermined with respect to the variable factors.³³

3.5.1 The Model

The model presented to test the instantaneous adjustment variable cost shares is given as:

$$S_{it} = b_i + \sum_j^n b_{ij} \ln p_{jt} + b_{kt} \ln k_{t-1} + b_{iQ} \ln Q + b_{it} \ln(t) \quad 3.47$$

where $i, j = K, L, E, M$ and S_{it} is again the factor demand shares,

³² Jane Friesen Testing Dynamic Specification of Factor Demand Equations For The U.S. Manufacturing. The Review of Economics and Statistics p. 240.

³³ *ibid.* p. 241.

p_{jt} is the price of the j^{th} factor, k_{t-1} is the previous period capital stock, Q is output, and the b_{ij} 's are parameters. This share equation does not impose homogeneity, symmetry, or homotheticity and represents nonneutral technical change.³⁴

The general first order dynamic model developed by Anderson and Blundell is given by:

$$\Delta S(t) = \Gamma \Delta x^*(t) - A^n(S_n(t-1) - \Pi_n x(t-1)) + \varepsilon(t) \quad 3.48$$

where ΔS_t is a vector of first differences of factor shares, Δx^*_t is a vector of first differences of regressors, excluding the intercept term, x_{t-1} is a vector of lagged values of all regressors, including the constant term, Γ and A^n are coefficient matrices and Π is a matrix of steady state coefficients (ie) those in 3.47 above.³⁵

In order to generate a nonsingular system one equation is deleted from the above system of equations. The model to be estimated is then:

$$\Delta S_t^* = \Gamma \Delta X_t - C^*(S_{t-1}^* - \Pi X_{t-1}) + \varepsilon^* \quad 3.49$$

where C^* is:

$$C^* = \begin{bmatrix} C_{MM} - C_{ME} & C_{ML} - C_{ME} \\ C_{LM} - C_{LE} & C_{LL} - C_{LE} \end{bmatrix} \quad 3.50$$

³⁴ Jane Friesen "Testing Dynamic Specification of Factor Demand Equations For The U.S. Manufacturing." The Review of Economics and Statistics p. 241.

³⁵ *ibid.* p. 241.

This deletion is the same as deleting a row in C* corresponding to the element S_{t-1} which is the deleted share equation and also requires the deletion of the row B(0) corresponding to the same element.³⁶ The following would be a typical equation of 3.49:

$$\begin{aligned}
S_{it} - S_{it-1} &= \gamma_{iM}(\ln p_{Mt} - \ln p_{Mt-1}) \\
&+ \gamma_{iL}(\ln p_{Lt} - \ln p_{Lt-1}) \\
&+ \gamma_{iE}(\ln p_{Et} - \ln p_{Et-1}) \\
&+ \gamma_{iy}(\ln y_t - \ln y_{t-1}) \\
&+ \gamma_{it}(\ln(t) - \ln(t-1)) \\
&+ C_{iM}^* S_{Mt-1} - C_{iL}^* S_{Lt-1} \\
&+ C_{iM}^* b_M + C_{iL}^* b_L \\
&+ [C_{iM}^* b_{MM} + C_{iL}^*] \ln p_{Mt-1} \\
&+ [C_{iM}^* b_{ML} + C_{iL}^* b_{LM}] \ln p_{Lt-1} \\
&+ [C_{iM}^* b_{ME} + C_{iL}^* b_{LE}] \ln p_{Et-1} \\
&+ [C_{iM}^* b_{MK} + C_{iL}^* b_{LK}] \ln k_{t-2} \\
&+ [C_{iM}^* b_{MQ} + C_{iL}^*] \ln Q_{t-1}
\end{aligned}$$

³⁶ *ibid.* p. 242.

$$+ C_{iM}^* b_{MT} + C_{iL} b_{LT}] \ln(t-1) + \varepsilon_{it}^* \quad 3.51$$

The model is estimated using annual time series data from 1947-1991. To test the results of instantaneous adjustment maximum likelihood methods are used. In addition to this Friesen tests the exogeneity of input prices and output using a method developed by Greke.³⁷

3.5.2 The Empirical Results

The first static model Friesen estimates treats capital as quasi-fixed, and energy, labour and materials as variable inputs. This model is obtained by imposing the following set of restrictions on 3.49:

$$C_{ii}^* = 1, C_{ij}^* = 0, \gamma_{ij} = b_{ij}, \gamma_{ik} = b_{ik},$$

$$\gamma_{iy} = b_{iy}, \gamma_{it} = b_{it} \quad 3.52$$

In addition to the above tests likelihood ratio tests were performed on the share equations with symmetry, neutral technological change, and homotheticity being imposed.

For the model the exogeneity of input prices and output was rejected. The model was then reestimated using three stage least squares with lagged exogenous variables as instruments. Again the model is rejected for both the instantaneous and symmetric versions. However for homotheticity and neutral technological change the model was not rejected. If symmetry is added to the model with these

³⁷ *ibid.* p. 242.

restrictions then the new model is rejected.

Friesen now turns from the static model to the error correction model, in effect assuming that not all of the variable shares will not adjust instantaneously. The model that Friesen uses to test this is:

$$\begin{aligned}
 S_{it} - S_{it-1} = & \gamma_{iM}(\ln p_{Mt} - \ln p_{Mt-1}) \\
 & + \gamma_{iL}(\ln p_{Lt} - \ln p_{Lt-1}) \\
 & + \gamma_{iE}(\ln p_{Et} - \ln p_{Et-1}) \\
 & + \gamma_{iK}(\ln K_t - \ln K_{t-1}) \\
 & + \gamma_{it}(\ln(t) - \ln(t-1)) \\
 & - C_{iM}S_{Mt-1} - C_{iL}S_{Lt-1} \\
 & - C_{iE}S_{Et-1} - C_{iK}S_{Kt-1} \\
 & + C_{iM}b_M + C_{iL}b_L + C_{iE}b_E \\
 & + [C_{iM}b_{ML} + C_{iL}b_{LM} + C_{iE}b_{EM} + C_{iK}b_{KL}] \ln p_{Mt-1} \\
 & + [C_{iM}b_{ME} + C_{iL}b_{LE} + C_{iE}b_{EL} + C_{iK}b_{KE}] \ln p_{Lt-1} \\
 & + [C_{iM}b_{MK} + C_{iL}b_{LK} + C_{iE}b_{EK} + C_{iK}b_{KK}] \ln p_{Kt-1} \\
 & + [C_{iM}b_{ME} + C_{iL}b_{LE} + C_{iE}b_{EE} + C_{iK}b_{KE}] \ln p_{Et-1} \\
 & + [C_{iM}b_{MY} + C_{iL}b_{LY} + C_{iE}b_{EY} + C_{iY}b_{KE}] \ln Y_{t-1} \\
 & + [C_{iM}b_{MT} + C_{iL}b_{LT} + C_{iE}b_{ET} + C_{iT}b_{KT}] \ln(t-1) \qquad 3.53
 \end{aligned}$$

The static, partial adjustment, and autoregressive models are nested within 1.102. Namely:

$$i) \gamma_{ij} = b_{ij} \text{ autoregressive} \qquad 3.54$$

$$\text{ii) } \gamma_{ik} = \sum_k C_k b_{kj} \text{ partial adjustment} \quad 3.55$$

$$\text{iii) i) or ii) and } C_{i1} = 0 \text{ } C_{1j} = 1 \text{ static} \quad 3.56$$

Friesen begins with the most general representation and adopts the following strategy. First homogeneity, and homogeneity and symmetry are tested. Second the static, partial adjustment, and autoregressive models are tested. The results of these tests are as follows: the partial adjustment model is rejected; the autoregressive model is accepted at the 1% level but not at the 2.5% level; and the static model is also rejected when tested against the autoregressive model³⁸

The autoregressive model is then considered to be the appropriate model. Homotheticity and neutral technological change are then tested and rejected as are homogeneity and homogeneity and symmetry.

Next Friesen examines some elasticity estimates generated by the error correction model. She notes that previous studies on the Berndt and Wood data set are able to generate negative own price elasticities. She concludes that all three models are unable to generate negative own price elasticities.

In summation Friesen notes that the error correction model does not perform well in the sense of rejecting homogeneity and homogeneity and symmetry as well as not being able to generate negative own price elasticities.

³⁸ *ibid.* p. 243.

3.6 Summary of the Literature Review

The results of estimating the static model are contradictory in the sense that Berndt and Wood as well as Fuss find energy capital complementary while Griffon and Gregory find substitutability. This could be for a number of reasons including different data sets and approaches to measuring input quantities and prices and varied treatments of excluded inputs and distinctions between short and long run elasticities.

In the Berndt Wood study as well as the Fuss study homogeneity and symmetry are assumed and not tested for so we do not know whether the theory is violated or not.

Furthermore the dynamic model does not in general outperform the static model in terms of accepting the tenants of neoclassical theory, namely homogeneity and symmetry.

Table 3.1 Restrictions on the First Difference Model

| | |
|---|--|
| $B_s = I \forall s, \Gamma_s = \Pi \forall s$ | Static Model |
| $B(L) = 0, A = 0, \Gamma_0 = \Pi_1,$ and $\Gamma_s = 0$ for $s \geq 1$ | Dynamic Model |
| $\Gamma(L) = (1 + B(L))\Pi_1, p = q$ | Static Model with Vector Autoregressive of Order p |
| $\Gamma_0 = A\Pi_1, \text{ and } p = q = 1$ | Partial Adjustment Model |

CHAPTER 4 THE ENERGY SUBMODEL

The methodology followed in this Capital, Labour, and Energy study of eleven Canadian Industrial sectors is a two step procedure. As a first step I estimate an energy submodel by assuming that energy is weakly separable from the production function. As a second step I estimate a dynamic as well as a static capital, labour, energy input share model. Both models are estimated in a multivariate regression with the same independent variables on the right hand side of the equation and identically independently distributed error terms using iterative generalized least squares in SHAZAM.³⁹ This can be expressed as:

$$\begin{aligned}
 S_1 &= \alpha_0 + \beta_{11}X_1 + \beta_{12}X_2 + \dots + \beta_{1n}X_n + \epsilon_1 \\
 &\cdot \\
 &\cdot \\
 S_n &= \alpha_n + \beta_{n1}X_1 + \beta_{n2}X_2 + \dots + \beta_{nn}X_n + \epsilon_n
 \end{aligned}
 \tag{4.1}$$

4.1 The Model

The energy submodel consists of energy being an aggregate of six component types. These are gasoline, fuel oil, electricity, coal and coke, natural gas, and liquid petroleum gas. Details of the data construction are given in Appendix A while the list of the various industries is given in Table

³⁹ Kmenta Elements of Econometrics pp. 607-616.

4.1 at the end of this chapter.⁴⁰ The data set was chosen from a time series sample of twenty Canadian industrial sectors from 1963 to 1984 which was narrowed to eleven industries because the series on coal and coke and natural gas were not continuous.

4.1.1 The Assumed Technology

I construct the energy submodel by assuming the following technology:

$$Q = f(E_1, \dots, E_n, L, K). \quad 4.2$$

Now imposing homothetic weak separability we arrive at the following form of the production function:

$$Q = g(E(E_1, \dots, E_n), L, K) \quad 4.3$$

Where $E(E_1, \dots, E_n)$ is an energy aggregate that is homogeneous of degree one in its arguments. The corresponding cost function is also weakly separable:

$$C = C(p_E(p_{E_1}, \dots, p_{E_n}), p_L, p_K, Q) \quad 4.4$$

Where p_E is an aggregate price index defined by a function $p_E(p_{E_1}, \dots, p_{E_n})$ that denotes the minimal unit cost at prices $(p_{E_1}, \dots, p_{E_n})$, of the energy aggregate.

I assume that p_E can be represented in a translog form:

$$\ln p_E = \ln \beta_0 + \sum_i \beta_i \ln p_{E_i} + 1/2 \sum_i \sum_j \beta_{ij} \ln p_{E_i} \ln p_{E_j} \quad 4.5$$

⁴⁰ The data come from three Statistics Canada publications which are, Consumption of Purchased Fuels and Electricity, Fixed Capital Flows and Stocks, and Manufacturing Industries of Canada.

This leads to the following input share system:

$$S_{E1} = \beta_1 + \sum_j \beta_{1j} \ln p_{E1} \quad 4.6$$

The restrictions of neoclassical production theory imply:

$$\sum_1 \beta_1 = 1 \quad 4.7$$

$$\sum_1 \beta_{1j} = \sum_j \beta_{j1} = 0 \quad 4.8$$

$$\beta_{1j} = \beta_{j1} \quad 4.9$$

The system of 4.6 is estimated subject to the restrictions outlined above then we use the results of this estimation to arrive at an estimate of $\ln p_E$ (actually $\ln(p_E/\beta_0)$).

I estimate the following model using time series data (1963-1984) for the eleven Canadian industrial sectors.

$$S_{E1} = \beta_1 + \sum_1 \beta_{1j} \ln p_{E1} + V_t \quad 4.10$$

where V is a vector of random disturbances assumed to be identically independently distributed. Since the input demand shares by definition sum to unity the system of equations as presented are singular. To compensate for this one equation is deleted from the system. I arbitrarily delete the sixth equation; this corresponds to the liquid petroleum gas fuel type.

4.1.2 The Empirical Results

The results of the estimation for the eleven industries

are given in tables B.1 to B.11 in Appendix B. The t ratios for each coefficient are all quite reasonable indicating that the majority of the coefficients are significantly different from zero. The R^2 are for the most part quite high indicating a rather good fit for each equation. And the Durbin Watson test statistics are all rather low indicating the presence of serial correlation suggesting that a more dynamic approach may be in order for this data set.

4.1.3 The Allen Elasticities of Substitution

These results together with the input share values allow us to calculate the Allen Elasticities of Substitution (AES) as well as the price elasticities (the input shares equations are taken at their mean). The standard errors for these variables were not computed due to the nonlinearities involved. I present the results of these calculation in Appendix C where table C.1 indicates the fuel types and tables C.2 to C.12 present the AES's.

There are some restrictions placed on the AES matrices by economic theory. Theory states that the AES matrices should be negative semidefinite and singular. A necessary but not sufficient condition for the negative semidefiniteness of a matrix is that all of the diagonal elements of that matrix be nonpositive, this implies that all the σ_{ii} 's are nonpositive. A sufficient condition is that all nonzero characteristics roots are negative. A cost function is said to be globally concave if the AES matrices are negative semidefinite for all

the input prices. In this paper I examine them only locally for the mean of the prices.

For the rubber and plastics industry some of the σ_{ii} 's are positive therefore these results do not conform with economic theory. Apart from this 22 of the remaining AES's are positive indicating a high degree of interfuel substitution.

Note that all except one of the σ_{ii} 's are negative for the wood industry and that 18 of the remaining 30 are positive suggesting only a moderate degree of interfuel substitution.

In the furniture and fixtures industry all of the own price elasticities are negative indicating the results do conform with part of economic theory. Whereas 18 of the remaining elasticities are positive indicating only a moderate degree of interfuel substitution.

For the paper and allied industry all of the diagonal elements are negative indicating that the results are in agreement with part of economic theory. Otherwise 18 of the remaining 30 Allen elasticities of substitution are positive indicating a moderate degree of interfuel substitution.

For the primary metals industry the tenets of neoclassical theory are again violated as not all of the own price elasticities are negative. In addition to this 18 of the remaining 30 AES's are positive which indicates a moderate degree of interfuel substitution.

The results for the AES for the metal fabricating industry are not in agreement with economic theory as not all

of the diagonal elements are negative. In addition to this 18 of the remaining 30 AES's are positive which shows an average degree of interfuel substitution.

Once more, for the machinery industry not all of the σ_{11} 's are negative which is in direct conflict with economic theory. Apart from this only 16 of the remaining elasticities are positive suggesting a moderate degree of interfuel substitution.

Again for the transportation equipment industry we find that all of the own AES's are negative which does conform with economic theory. Apart from this 20 of the remaining 30 elasticities are positive indicating a high degree of interfuel substitution.

For the electrical products industry not all of the diagonal elements are negative indicating that neoclassical production theory is not validated. Otherwise 16 of the 30 AES's are negative indicating a moderate amount of complements in the electrical products industry.

Economic theory is validated for the non-metallic mineral products as all of the own price elasticities are negative. Of the remaining 30 AES's 24 are positive indicating a high degree of interfuel substitution.

Once more not all of the σ_{11} 's are negative in the chemical and chemical products industry indicating that economic theory is not validated. Apart from this 22 of the 30 other elasticities are positive indicating a high degree of

substitutability.

In summation the results of estimating the Allen Elasticities of Substitution are rather poor. The fact that for 8 of the 11 industries the σ_{ii} 's are not all positive indicates that these results do not conform very well with economic theory. Apart from this the results do indicate a moderate degree of interfuel substitution. Also the results do conform with Fuss's study which used aggregate pooled data for the entire Canadian industrial sector. Fuss finds not all of the own price elasticities are negative but all of the other AES's are positive.

4.1.4 The Characteristic Roots

The characteristics roots are summarized at the end of this chapter in Table 4.2. In all of the industries one of the roots is zero indicating that the matrices are singular. However, in none of the industries are all of the roots all negative indicating that none of the matrices are negative semidefinite which means none of the underlying cost functions are concave. The degree to which concavity is violated can be determined by examining the roots and their magnitude.

In the rubber and plastics industry there are two positive roots with one being substantially so indicating that concavity is strongly violated. In the wood industry two of the roots are positive but only moderately so indicating concavity is not strongly rejected. For the furniture and fixtures industry one root is positive but small therefore

concavity is only mildly rejected. For the paper and allied products industry only one root is positive and relatively small so concavity is again mildly rejected. In the primary metals two roots are positive but not substantially so indicating that concavity is not strongly rejected. In the metal fabricating industry two of the roots are positive but not substantially so indicating that there was not a strong violation of concavity. For the machinery industry two of the roots are again positive with one being moderately so indicating concavity is moderately rejected. In the transportation industry two of the roots are positive but to the extent that concavity is only violated moderately. The electrical products industry has one large positive root indicating that concavity is strongly rejected. In the non-metallic minerals industry there are two very small positive roots indicating that concavity is only moderately rejected. Finally in the chemical and chemical products roots there is one very small positive root indicating that concavity is only moderately rejected. We now turn our attention to the price elasticities. Recall the relationship between the AES and the price elasticities of substitution:

$$E_{1j} = S_j \sigma_{1j}. \quad 4.11$$

Since the factor shares are always positive the own price elasticities are a positive monotonic transformation of the AES. Therefore all of the signs of the E_{1j} 's are as that of the AES's, and the only change in the price elasticities is

the magnitude. Little can be gained by commenting on them directly so they are relegated to appendix D in tables D.1 to D.11.

Table 4.1 The Industrial Sectors

| <u>Industry Number</u> | <u>Industry Name</u> |
|------------------------|--------------------------------|
| 3. | Rubber and Plastic Products |
| 8. | Wood |
| 9. | Furniture and Fixtures |
| 10. | Paper and Allied Industries |
| 12. | Primary Metals |
| 13. | Metal Fabricating |
| 14. | Machinery |
| 15. | Transportation Equipment |
| 16. | Electrical Products |
| 17. | Non-metallic Mineral Products |
| 19. | Chemical and Chemical Products |

Table 4.2 Characteristics Roots for the AES matrices

| industry | λ_1 | λ_2 | λ_3 | λ_4 | λ_5 | λ_6 |
|------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Rubber and | | | | | | |
| Plastics | 3353.1543 | -123.8595 | -37.4014 | 4.0882 | -11.9963 | .0000 |
| Wood | -502.3405 | -13.1805 | 8.0952 | -6.6081 | .0000 | 2.4245 |
| Furniture and | | | | | | |
| Fixtures | -161.7070 | -47.4789 | 27.1523 | -11.1209 | .0000 | -.2288 |
| Paper and Allied | | | | | | |
| Products | -125.5846 | -93.7660 | -19.7273 | -11.7891 | .0000 | .3881 |
| Primary Metals | | | | | | |
| Metal | -87.1548 | -50.1776 | 20.6743 | -7.7537 | .7829 | .0000 |
| Fabricating | -424.6187 | 77.9413 | -17.4258 | 2.9923 | .0000 | -11.8983 |
| Machinery | -154.8941 | 117.9635 | -26.7503 | 2.7044 | -10.3359 | .0000 |
| Transportation | | | | | | |
| Equipment | -66.5931 | 27.8324 | -18.0560 | -8.7714 | .0000 | .2978 |
| Electrical | | | | | | |
| Products | -1047.7547 | 148.5022 | -22.1239 | -6.6652 | .0000 | -2.8918 |

Table 4.2 continued

| industry | λ_1 | λ_2 | λ_3 | λ_4 | λ_5 | λ_6 |
|-------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Non-metallic | | | | | | |
| Minerals | -21.7082 | -11.1216 | 4.3460 | -2.6688 | .4120 | .0000 |
| Chemical and | | | | | | |
| Chemical Products | -34.6455 | -14.9642 | -6.1951 | 2.1190 | .0000 | -.4220 |

CHAPTER 5 THE STATIC MODEL

5.1 The Model

The second stage of this study is the estimation of the KLE model. This model is estimated in two ways, the static model and the dynamic model. In chapter 5 we estimate the static version while in chapter 6 we estimate the dynamic model. In estimating both models tests are performed for HNTC, homotheticity, homogeneity, and symmetry. Again a multivariate regression analysis is done using iterative generalized least squares with the model being:

$$\begin{aligned} S_1 &= \alpha_{10} + \beta_{11}X_1 + \dots + \beta_{1n}X_n + \epsilon_1 \\ S_2 &= \alpha_{20} + \beta_{21}X_1 + \dots + \beta_{2n}X_n + \epsilon_2 \end{aligned} \quad 5.1$$

where the error terms are identically independently distributed.

For the static method it is assumed that there exists a twice differentiable production function for each of the eleven industrial sectors. This function is assumed to be weakly separable in the six types of energy. This function can be represented as:

$$Q = f(E_1, \dots, E_6, L, K) \quad 5.2$$

with homothetic weak separability the following production function is arrived at:

$$Q = g(E(E_1, \dots, E_6), L, K) \quad 5.3$$

The corresponding weakly separable cost function is:

$$C = C(p_E(p_{E_1}, \dots, p_{E_6}), p_L, p_K, Q) \quad 5.4$$

I choose the following quadratic translog representation of 5.3:

$$\begin{aligned} \ln C = & \alpha_0 + \alpha_Q \ln Q + \sum_i \alpha_i \ln p_i + 1/2 \sum_i \sum_j \beta_{ij} \ln p_i \ln p_j \\ & + \sum_i \beta_{Qi} \ln Q \ln p_i + \beta t + 1/2 \beta_{TT} t^2 \\ & + \beta_{TQ} \ln Q + \sum_i \beta_{Ti} t \ln p_i \end{aligned} \quad 5.5$$

where $i, j = K, L, E$, t is a time trend, and p_E is derived from chapter 4.

5.1.1 The Share Equations

Through logarithmic differentiation and application of Shepherd's lemma we arrive at the following input demand shares:

$$S_K = \alpha_K + \sum_{i=K}^E \beta_{Ki} \ln p_i + \beta_{KT} t + \beta_{KQ} \ln Q$$

$$S_L = \alpha_L + \sum_{i=K}^E \beta_{Li} \ln p_i + \beta_{LT} t + \beta_{LQ} \ln Q$$

$$S_E = \alpha_E + \sum_{i=K}^E \beta_{Ei} \ln p_i + \beta_{ET} t + \beta_{EQ} \ln Q \quad 5.6$$

This allows me to test for HNTC and homotheticity by imposing the restrictions that β_{iT} and β_{iQ} are equal to zero.

Assuming that random errors arise due to errors in the cost minimization behaviour, and adding time subscripts, we have the following set of estimatable equations:

$$S_{K_t} = \alpha_{K_t} + \sum_{i=K}^E \beta_{K_i} \ln p_{i_t} + \beta_{KT} T + \beta_{KQ} \ln Q_t + \epsilon_{Kt}$$

$$S_{L_t} = \alpha_{L_t} + \sum_{i=K}^E \beta_{L_i} \ln p_{i_t} + \beta_{LT} T + \beta_{LQ} \ln Q_t + \epsilon_{Lt}$$

$$S_{E_t} = \alpha_{E_t} + \sum_{i=K}^E \beta_{E_i} \ln p_{i_t} + \beta_{ET} T + \beta_{EQ} \ln Q_t + \epsilon_{Et} \quad 5.7$$

Where the ϵ_{it} 's are assumed to be independently identically distributed.

Again this set of equations is singular, therefore to estimate them I must delete one of the equations. I arbitrarily delete the Labour equation.

5.1.2 HNTC and Homotheticity

I now proceed to test the restrictions of HNTC and homotheticity. The results for the eleven industries are summarized in Table 5.1.

Hicks neutral technological change is rejected in all but three of the industries, which are paper and allied products, primary metals, and non-metal mineral products. Homotheticity is accepted in the primary metals and the electrical products industries. And both homotheticity and HNTC are accepted in

the primary metals industry.

5.1.3 Homogeneity and Symmetry

We now turn our attention to the tenets of neoclassical production theory, namely homogeneity and symmetry. Again a likelihood ratio test is performed with the maintained hypothesis being the absence of homogeneity and symmetry. The results of these tests are summarized in tables 5.2.

Homogeneity is not rejected in one of the eleven industries, namely the chemical and chemical products industry, while homogeneity and symmetry are not rejected in only the paper and allied industry. Otherwise both homogeneity and symmetry are strongly rejected in all the other industries. In conclusion I can say that these results do not conform very well with the tenets of neoclassical production theory. The results are not surprising because in studies involving static models it is not uncommon to reject homogeneity and symmetry. Also it is common, see for example the Fuss and Berndt and Wood study, to assume homogeneity and symmetry and not to test for them.

5.1.4 The Empirical Results

Finally the estimated equations are presented in Tables E.1 through E.11 in Appendix E. The t ratios are for the most part statistically different from zero, while all of the R^2 's are high suggesting a good fit for the model. However, the low Durbin Watsons indicate that a more dynamic approach may be in order. The coefficients derived here are used to

calculate the AES and price elasticities. These are presented in tables F.1 through F.11 and G.1 through G.11 in Appendixes F and G.

In only 4 of the 11 industries are all of the own price elasticities negative. These are furniture and fixtures, paper and allied products, transportation equipment, and chemical and chemical products. This is not in line with economic theory as they all should be negative but as Anderson and Blundell note it is common in static models for the postulates of economic theory to be violated.

Table 5.3 summarizes the input substitution pattern for the various industries. Capital and labour are substitutes in 10 out of the 11 industries, which is in line with other studies. Capital and energy are substitutes in 10 of the 11 industries, this contradicts the results of Berndt and Wood but confirms the results of Gregory and Griffon. Energy and labour are complements in 9 out of the 11 industries which contradicts the work of both Gregory and Griffon as well as Berndt and Wood.

5.1.5 Serial Correlation

The low Durbin Watsons indicate that a more dynamic approach may be in order. I perform tests for an AR(1) specification of the error terms. This is given as:

$$\varepsilon_t = \rho\varepsilon_{t-1} + v_t, \quad 0 < \rho < 1$$

Where v_t is identically independently distributed with 0 mean and constant variance and is uncorelated with ε and all of the

independent variables. This positive first order correlation in the residuals is likely because of the high degree of correlation over time present in the cumulative effects of omitted variables in the regression model.⁴¹

The test statistics for the null hypothesis of no positive serial are the critical values of the Durbin Watson. This statistic has a lower, d_1 , and an upper, d_u , value which are dependent upon the number of observations. If the calculated Durbin Watson (DW) is below d_1 then the null hypothesis is rejected if it is above d_u then the null hypothesis is not rejected. If the value of the test statistic lies in between these bounds then the test is inconclusive.

For 24 sample points, 5 regressors excluding the intercept, and a 5 percent significance level the lower value is .93 and 1.90 for the upper bound. For the capital equation the hypothesis of no serial correlation is not rejected in the rubber and plastics and the machinery industries. The hypothesis is rejected only in the wood industry and for all other industries the test is inconclusive. For the energy equation the hypothesis of and AR(1) specification is rejected only in the paper and allied industry. For all other industries the test is inconclusive.

In addition to the formal Durbin Watsons tests plots of

⁴¹ Pindyck R., and Rubinfeld D., L. Econometric Models and Economic Forecasts p. 153.

the residuals vrs. the predicted values are given in Appendix R1. These plots are done because of the inability of the Durbin Watson test to reject or not reject the presence of serial correlation. For the most part the residuals display their autocorrelation by their cyclical pattern and their proximity to one another.

5.1.6 The Characteristic Roots

In addition to the own price elasticities being negative economic theory also states that each matrix be singular and negative semidefinite. The local negative semidefiniteness is a necessary and sufficient condition for the concavity of the cost function. I test this by examining the characteristic roots or eigenvalues for each matrix. The results are summarized in Table 5.4 at the end of this chapter. In order for the matrix to be singular one of the roots must be zero, or approximately so, this is the case for all the matrices. In order for the matrix to be negative semidefinite two of the roots must be negative. The furniture and fixtures, transportation equipment, and chemical and chemical products matrices are negative semidefinite.

Again I note that the price elasticities are a mirror image of the AES the only difference in them being their magnitude. They are presented in appendix G at the end of this document.

Table 5.1 The Static Model: Tests for HNTC, Homotheticity, Homotheticity and HNTC⁴²

| Industry | HNTC | Homotheticity | HNTC and Homotheticity |
|-------------------|----------|---------------|------------------------|
| | χ^2 | χ^2 | χ^2 |
| Rubber and | | | |
| Plastics | 27.3078 | 37.9246 | 84.9038 |
| Wood | 11.0902 | 27.5370 | 32.0156 |
| Furniture and | | | |
| Fixtures | 15.7030 | 13.8868 | 48.4836 |
| Paper and Allied | | | |
| Products | 0.4516 | 11.6340 | 15.8478 |
| Primary Metals | 1.3076 | 3.1176 | 8.0044 |
| Metal Fabricating | 18.9396 | 21.6486 | 50.1932 |
| Machinery | 18.4240 | 37.3586 | 51.1908 |
| Transportation | | | |
| Equipment | 34.9474 | 26.2168 | 48.0300 |

⁴² Critical Value at the $\alpha = .01$ level for 2 degrees of freedom is 9.210 and for 4 degrees of freedom 13.277.

Table 5.1 continued

| Industry | HNTC | Homotheticity | HNTC and Homotheticity |
|-------------------|----------|---------------|------------------------|
| | χ^2 | χ^2 | χ^2 |
| Electrical | | | |
| Products | 11.4466 | 8.2926 | 37.5646 |
| Mon-metal Mineral | | | |
| Products | 9.1924 | 21.4294 | 68.8386 |
| Chemical and | | | |
| Chemical Products | 20.7868 | 18.0850 | 40.3638 |

Table 5.2 The Static Model: Tests for Homogeneity and Symmetry⁴³

| Industry | Homogeneity | Homogeneity and Symmetry |
|-------------------|-------------|--------------------------|
| | χ^2 | χ^2 |
| Rubber and | | |
| Plastics | 44.1986 | 44.7806 |
| Wood | 51.4198 | 52.7446 |
| Furniture and | | |
| Fixtures | 27.5370 | 32.0156 |
| Paper and | | |
| Allied Products | 10.4682 | 11.1182 |
| Primary Metals | 43.6078 | 44.0350 |
| Metal Fabricating | 46.9834 | 50.3558 |
| Machinery | 20.5650 | 21.0776 |
| Transportation | | |
| Equipment | 36.6200 | 42.1930 |

⁴³ Critical values for $\alpha = .01$ for 2 degrees of freedom 9.210 and for 3 degrees of freedom 11.345.

Table 5.2 continued

| Industry | Homogeneity | Homogeneity and Symmetry |
|-----------------------|-------------|--------------------------|
| | χ^2 | χ^2 |
| Electrical | | |
| Products | 40.8244 | 40.9874 |
| Non-metallic | | |
| Minerals | 23.4446 | 68.8386 |
| Chemical and Chemical | | |
| Products | 7.3068 | 19.5688 |

Table 5.3 The Static Model: Input Substitution Patterns

| industry | σ_{KL} | σ_{KE} | σ_{EL} |
|---------------------|---------------|---------------|---------------|
| Rubber and | | | |
| Plastics | substitutes | substitutes | complements |
| Wood | substitutes | substitutes | complements |
| Furniture and | | | |
| Fixtures | substitutes | substitutes | complements |
| Paper and Allied | | | |
| Products | substitutes | substitutes | complements |
| Primary Metals | substitutes | substitutes | complements |
| Metal Fabricating | substitutes | complements | substitutes |
| Machinery | complements | substitutes | complements |
| Transportation | | | |
| Equipment | substitutes | substitutes | complements |
| Electrical Products | substitutes | substitutes | complements |
| Non-Metallic | | | |
| Minerals | substitutes | substitutes | complements |
| Chemical and | | | |
| Chemical Products | substitutes | substitutes | substitutes |

Table 5.4 The Static Model: Characteristics Roots for the AES Matrices

| <u>industry</u> | <u>λ_1</u> | <u>λ_2</u> | <u>λ_3</u> |
|-------------------|-------------------------------|-------------------------------|-------------------------------|
| Rubber and | | | |
| Plastics | 2.4610 | -3.2843 | .0000 |
| Wood | 7.0229 | -5.8195 | .0000 |
| Furniture and | | | |
| Fixtures | -1.6870 | .0000 | -2.8528 |
| Paper and Allied | | | |
| Products | -22.0413 | -1.7911 | .0000 |
| Primary Metals | -26.4162 | 5.9548 | .0000 |
| Metal | | | |
| Fabricating | 11.5546 | -4.1888 | .0000 |
| Machinery | 5.5948 | -4.7781 | .0000 |
| Transportation | | | |
| Equipment | -7.8002 | .0000 | -2.3752 |
| Electrical | | | |
| Products | 69.3658 | -30.3561 | .0000 |
| Non-metallic | | | |
| Minerals | 15.3383 | -12.9895 | .0000 |
| Chemical and | | | |
| Chemical Products | -32.1490 | -16.2753 | .0000 |

CHAPTER 6 THE DYNAMIC MODEL

Following the methodology of Anderson and Blundell I now explore the possibility of estimating and testing a capital, labour, and energy model within a general dynamic specification of a demand system.

6.1 The Model

The reader should recall that the four models, static, partial adjustment, autoregressive, and dynamic can be derived from a first order difference equation. The dynamic model equation is given as:

$$\begin{aligned} \Delta S(t) = \Gamma x^*(t) - A^n(S_n(t-1) - \\ - \Pi_n X(t-1)) + \varepsilon(t) \end{aligned} \quad 6.1$$

where the $x(t)$'s are the prices of the different factors, the $S_n(t-1)$ are the input shares, and Δ is a first difference operator. The static model is represented by:

$$S(t) = \Pi x(t) + \varepsilon(t) \quad 6.2$$

The static model with autoregressive errors is given by:

$$S(t) = \Pi x(t) + u(t) \quad 6.3$$

where

$$u(t) = R^n u(t-1) + \varepsilon(t) \quad 6.4$$

Finally the partial adjustment model is given by:

$$\Delta S(t) = M(\Pi x(t) - S(t-1)) + \varepsilon(t) \quad 6.5$$

6.1.1 The Time Series Format

Equations 4.1, 4.2, 4.3, and 4.5 can be parameterized in

either a time series form or a demand system format for means of estimation. The time series variation for the static model, not assuming Hicks neutral technological change and not assuming homotheticity , is given by:

$$S_1 = \alpha_1 + \beta_{11} \ln P_K + \beta_{12} \ln P_L + \beta_{13} \ln P_E + \beta_{t1} t + \beta_{Q1} \ln Q \quad 6.6$$

where t is again a time index.

The times series model for the partial adjustment model, again not assuming Hicks Neutral Technological Change and not assuming homotheticity is:

$$S_1 = \alpha_1 + \beta_{11} \ln P_K + \beta_{12} \ln P_L + \beta_{13} \ln P_E + \gamma_{11} S_{K_{t-1}} + \gamma_{12} S_{L_{t-1}} + \gamma_{13} S_{E_{t-1}} + \beta_{t1} t + \beta_{Q1} \ln Q \quad 6.7$$

For the dynamic model the time series specification is given by:

$$S_1 = \alpha_1 + \beta_{11} \ln P_K + \beta_{12} \ln P_L + \beta_{13} \ln P_E + \gamma_{11} S_{K_{t-1}} + \gamma_{12} S_{L_{t-1}} + \gamma_{13} S_{E_{t-1}} + \delta_{11} P_{K_{t-1}} + \delta_{12} P_{L_{t-1}} + \delta_{13} P_{E_{t-1}} + \beta_{T1} T + \beta_{Q1} \ln Q + \delta_{14} \ln Q_{t-1} \quad 6.8$$

And finally, for the autoregressive model the time series format is given by:

$$S_1 = \alpha_1 + \beta_{11} \ln P_K + \beta_{12} \ln P_L + \beta_{13} \ln P_K + B_1 \ln Q + \gamma_{11} S_{K_{t-1}} + \gamma_{12} S_{L_{t-1}} + \gamma_{13} S_{E_{t-1}}$$

$$\begin{aligned}
& + (\gamma_{11}\beta_{11} + \gamma_{12}\beta_{21}) \ln p_{K_{t-1}} \\
& + (\gamma_{11}\beta_{12} + \gamma_{12}\beta_{21+1}) \ln p_{L_{t-1}} \\
& + (\gamma_{11}\beta_{13} + \gamma_{12}\beta_{21+2}) \ln p_{E_{t-1}} \\
& + (\gamma_{11}B_1 + \gamma_{12}B_{1+1}) \ln Q_{t-1}
\end{aligned} \tag{6.9}$$

6.1.2 Model Identification

I now use a series of nested hypothesis tests to identify whether the underlying cost structure is static, partial adjustment, autoregressive, and dynamic. The tests are nested because the partial adjustment and autoregressive models are a special case of the dynamic model, and the static model is in turn a special case of the partial adjustment and autoregressive models. There is, however, no relationship between the autoregressive and partial adjustment model. The results of these tests are given in table 6.1. In nine of the eleven industries the dynamic model was not rejected, in the remaining two the autoregressive model was accepted. These two industries were the wood and primary metals industries.

6.1.3 HNTC and Homotheticity

As a second step I wished to identify the nature of technological change and homotheticity. The reader will recall that in the first stage of estimation Hicks Neutral Technological Change was not assumed nor was homotheticity. I therefore perform a second set of nested tests to determine these properties. The results for the eleven industries are

summarized in table 6.2. In the furniture and fixtures, paper and allied products, primary metals, metal fabricating, and transportation equipment Hicks neutral Technological Change is accepted. Furthermore in no industry is homotheticity or homotheticity and HNTC accepted.

Finally I wish to examine the tenets of neoclassical production theory, namely homogeneity and symmetry. Unfortunately this cannot be done within the confines of the time series specification of the model. I now introduce the fully parameterized demand system model.

6.2 The Fully Parameterized Demand Model

The fully parameterized demand model is the system of demand equations giving the shares as a function of the exogenous variables. For the static model there is no change between the time series model and the fully parameterized demand model which is given by:

$$S_i = \alpha + \beta_{11} \ln p_K + \beta_{12} \ln p_L + \beta_{13} \ln p_E \\ + \beta_{T1} T + \beta_{Q1} \ln Q \quad 6.10$$

The partial model is fully parameterized as:

$$\Delta S_i = \alpha_i - \gamma_{11} S_{K_{t-1}} - \gamma_{12} S_{L_{t-1}} - \gamma_{13} S_{E_{t-1}} \\ + (\gamma_{11} \beta_{11} + \gamma_{12} \beta_{21}) \ln p_L \\ + (\gamma_{11} \beta_{11+1} + \gamma_{12} \beta_{21+1}) \ln p_L \\ + (\gamma_{11} \beta_{11+2} + \gamma_{12} \beta_{31+2}) \ln p_E \\ + (\gamma_{11} \beta_1 + \gamma_{12} \beta_{1+1}) \ln Q \quad 6.11$$

The fully parameterized demand model for the autoregressive model is given as:

$$\begin{aligned}
 \Delta S_t &= \alpha_1 + \beta_{11} \Delta \ln p_K + \beta_{12} \Delta \ln p_L + \beta_{13} \Delta \ln p_E + \beta_1 \Delta \ln Q \\
 &- \gamma_{11} S_{K,t-1} - \gamma_{12} S_{L,t-1} - \gamma_{13} S_{E,t-1} \\
 &+ (\gamma_{11} \beta_{11} + \gamma_{12} \beta_{21}) \ln p_{K,t-1} \\
 &+ (\gamma_{11} \beta_{12} + \gamma_{12} \beta_{21+1}) \ln p_{L,t-1} \\
 &+ (\gamma_{11} \beta_{11+2} + \gamma_{12} \beta_{21+2}) \ln p_{E,t-1} \\
 &+ (\gamma_{11} \beta_1 + \gamma_{12} \beta_{1+1}) \ln Q_{t-1}
 \end{aligned} \tag{6.12}$$

Whereas the dynamic model is parameterized as:

$$\begin{aligned}
 \Delta S_t &= \alpha_1 + \beta_{11} \Delta \ln p_K + \beta_{12} \Delta \ln p_L + \beta_{13} \Delta \ln p_E + \beta_1 \Delta \ln Q \\
 &- \gamma_{11} S_{K,t-1} - \gamma_{12} S_{L,t-1} - \gamma_{13} S_{E,t-1} \\
 &+ (\gamma_{11} \delta_{11} + \gamma_{12} \delta_{21}) \ln p_{K,t-1} \\
 &+ (\gamma_{11} \delta_{12} + \gamma_{12} \delta_{22}) \ln p_{L,t-1} \\
 &+ (\gamma_{11} \delta_{13} + \gamma_{12} \delta_{23}) \ln p_{E,t-1} \\
 &+ (\gamma_{11} \beta_1 + \gamma_{12} \beta_{1+1}) \ln Q_{t-1}
 \end{aligned} \tag{6.13}$$

I now proceed to test homogeneity and homogeneity and symmetry against the hypothesis that neither is imposed. This again involves the use of multivariate regression analysis in SHAZAM and a nested set of likelihood ratio tests. The results are presented in table 6.3.

Again the results are disconcerting as only two of the eleven industries are homogeneous, namely the non-metallic

mineral products and the chemical and chemical products industries. None of the eleven industries are homogeneous and symmetric; in fact the hypothesis of homogeneity and homogeneity and symmetry are strongly rejected in most industries. This is not surprising because in studies involving dynamic models it is common to reject homogeneity and symmetry. This is the case in the Anderson and Blundell study and the Friesen paper.

Having identified the model we are now in a position to calculate the AES and the price elasticities. Tables H.1 to H.11 in Appendix H present the Allen elasticities of substitution, while the price elasticities are given in tables I.1 to I.11 in the same Appendix I. The pattern of input substitution patterns are summarized in Table 6.4 at the end of this chapter.

The own price elasticities are negative in 7 of the 11 industries, which may be considered moderately good results. Capital and labour are substitutes in all 11 industries which tends to support most of the empirical work. Capital and energy are substitutes in 10 of the 11 industries which strongly supports the work of Gregory and Griffon but not Fuss and Berndt and Wood. And finally labour and energy are complements in 9 of the 11 industries which is not in agreement with any of the studies mentioned in this paper.

I again examine the characteristic roots of the AES matrices. The reader will recall that in order for the matrix

to be negative semidefinite two of the roots must be negative while in order for it to be singular one of the roots must be approximately zero. The roots are summarized in table 6.5. Again by construction all of the matrices are singular as indicated by a zero root. The cost function is concave for the furniture and fixtures, metal fabricating, non-metallic minerals, and chemical and chemical products.

Finally I present the final form of the actual equation that is to be presented in tables J.1 through J.11 in appendix J. Noting that for nine of the eleven industries the dynamic model is accepted as the maintained hypothesis while for the other two industries are autoregressive.⁴⁴

6.2.1 Serial Correlation

As indicated above all of the Durbin Watsons appear rather good indicating the absence of positive serial correlation. More formally I make use of the Durbin Watson test statistic outlined in section 5.1.5. The d_1 is for 15 independent variables is .221 and d_u is 3.251. For the rubber and plastics, wood, furniture and fixtures, electrical products, and machinery industries all of the DW are in the inconclusive range.⁴⁵

⁴⁴ In the primary metals industry both the autoregressive and partial adjustment models is accepted while the static model is rejected. Here the autoregressive model was chosen because it was more strongly accepted as indicated by a lower χ^2 .

⁴⁵ The practice in applied econometrics if the computed Durbin Watson lies between the lower and upper critical value range is to accept the hypothesis of no serial correlation.

For the metal fabricating and transportation equipment industry, which have 14 independent variables, the critical values of the Durbin Watsons are .239 and 3.193 which means the results of the test are again inconclusive.

For the industries with homogeneity, the non-metallic mineral products and the chemical and chemical products the critical values of the DW statistic are .335 and 2.983 so the test is again inconclusive.

For the two autoregressive models, paper and allied products and primary metals, the appropriate test statistics are .837 and 2.035. By inspection of Appendix J the reader can see that once more the test is inconclusive.

In addition to these formal tests plots of the residuals vrs. the fitted values are given in Appendix R2. Although the variance of the errors seems to increase over time for most of the industries the spiked pattern of the residuals indicates a random process indicating that hypothesis of no autocorrelation should not be rejected.

Table 6.1 The Dynamic Model: Model Identification⁴⁶

| industry | Autoregressive | Partial Adjustment | Static |
|-----------------|----------------|--------------------|----------|
| | χ^2 | χ^2 | χ^2 |
| Rubber and | | | |
| Plastics | 27.5148 | 27.1736 | 38.5588 |
| Wood | 20.0576 | 20.6216 | 54.6884 |
| Furniture and | | | |
| Fixtures | 61.1538 | 54.2154 | 20.7296 |
| Paper and | | | |
| Allied Products | 42.1732 | 52.6334 | 44.3744 |
| Primary Metals | 13.4384 | 17.0958 | 17.2602 |
| Metal | | | |
| Fabricating | 53.4500 | 53.6800 | 23.6592 |
| Machinery | 82.3008 | 82.5624 | 21.0781 |

⁴⁶ The critical value for the $\alpha=.01$ is 20.090 for 8 degrees of freedom and 13.277 for 4 degrees of freedom.

Table 6.1 continued

| industry | Autoregressive | Partial Adjustment | Static |
|-------------------|----------------|--------------------|----------|
| | χ^2 | χ^2 | χ^2 |
| Transportation | | | |
| Equipment | 58.7212 | 58.1752 | 21.4036 |
| Electrical | | | |
| Products | 66.0156 | 64.9968 | 19.1920 |
| Non-metallic | | | |
| Minerals | 27.7024 | 31.0854 | 5.4264 |
| Chemical and | | | |
| Chemical Products | 20.3632 | 21.6292 | 10.0630 |

Table 6.2 The Dynamic Model: Tests for HNTC, Homotheticity, and Homotheticity and HNTC⁴⁷

| Industry | HNTC | Homotheticity | HNTC and Homotheticity |
|-------------------|----------|---------------|------------------------|
| | χ^2 | χ^2 | χ^2 |
| Rubber and | | | |
| Plastics | 20.9914 | 41.3022 | 55.2628 |
| Wood | 10.3894 | 24.8976 | 61.5616 |
| Furniture and | | | |
| Fixtures | 8.1108 | 31.5750 | 58.9892 |
| Paper and Allied | | | |
| Products | 0.1704 | 20.6430 | 55.9698 |
| Primary Metals | 0.1924 | 20.6430 | 55.9698 |
| Metal Fabricating | 9.0576 | 40.8128 | 53.2270 |
| Machinery | 32.9328 | 41.4988 | 77.8060 |
| Transportation | | | |
| Equipment | 6.6654 | 40.4432 | 56.2964 |

⁴⁷ Critical Values at the $\alpha = .001$ level for 2 degrees of freedom 9.210, for 4 degrees of freedom 13.277, and for 6 degrees of freedom 16.812.

Table 6.2 continued

| Industry | HNTC | Homotheticity | HNTC and Homotheticity |
|-------------------|----------|---------------|------------------------|
| | χ^2 | χ^2 | χ^2 |
| Electrical | | | |
| Products | 13.3610 | 37.2928 | 50.9758 |
| Mon-metal Mineral | | | |
| Products | 13.1894 | 35.5658 | 38.3056 |
| Chemical and | | | |
| Chemical Products | 17.4882 | 16.7628 | 32.6874 |

Table 6.3 The Dynamic Model: Tests for Homogeneity and Symmetry⁴⁸

| Industry | Homogeneity | Homogeneity and Symmetry |
|------------------------------|-------------|--------------------------|
| | χ^2 | χ^2 |
| Rubber and Plastics | 13.5630 | 13.8120 |
| Wood | 22.4864 | 28.0345 |
| Furniture and Fixtures | 13.8596 | 20.9232 |
| Paper and Allied Products | 16.9034 | 17.5420 |
| Primary Metals | 19.8932 | 19.9208 |
| Metal Fabricating | 16.7054 | 17.5420 |
| Machinery | 11.3710 | 21.0422 |
| | 39.9572 | 52.4794 |

⁴⁸ Critical values for the $\alpha=.01$ level, for two degrees of freedom 9.210 for three degrees of freedom 11.345.

Table 6.3 continued

| Industry | Homogeneity | Homogeneity and Symmetry |
|-----------------------|-------------|--------------------------|
| | χ^2 | χ^2 |
| Transportation | | |
| Equipment | 22.9376 | 27.0846 |
| Electrical | | |
| Products | 32.0274 | 38.5168 |
| Non-metallic | | |
| Minerals | 8.5750 | 16.7094 |
| Chemical and Chemical | | |
| Products | 8.4362 | 15.0832 |

Table 6.4 The Dynamic Model: Input Substitution Patterns

| <u>industry</u> | <u>σ_{KL}</u> | <u>σ_{KE}</u> | <u>σ_{EL}</u> |
|---------------------|---------------------------------|---------------------------------|---------------------------------|
| Rubber and | | | |
| Plastics | substitutes | substitutes | complements |
| Wood | substitutes | substitutes | complements |
| Furniture and | | | |
| Fixtures | substitutes | substitutes | complements |
| Paper and Allied | | | |
| Products | substitutes | substitutes | complements |
| Primary Metals | substitutes | substitutes | complements |
| Metal Fabricating | substitutes | complements | substitutes |
| Machinery | complements | substitutes | complements |
| Transportation | | | |
| Equipment | substitutes | substitutes | complements |
| Electrical Products | substitutes | substitutes | complements |
| Non-metallic | | | |
| Minerals | substitutes | substitutes | complements |
| Chemical and | | | |
| Chemical Products | substitutes | substitutes | substitutes |

Table 6.5 The Dynamic Model: Characteristics Roots for the AES Matrices

| <u>industry</u> | <u>λ_1</u> | <u>λ_2</u> | <u>λ_3</u> |
|-------------------|-------------------------------|-------------------------------|-------------------------------|
| Rubber and | | | |
| Plastics | 10.4044 | -3.1891 | .0000 |
| Wood | -11.2501 | 7.7653 | .0000 |
| Furniture and | | | |
| Fixtures | -25.5154 | -1.6460 | .0000 |
| Paper and Allied | | | |
| Products | -15.7093 | 1.0991 | .0000 |
| Primary Metals | | | |
| Metal | 19.4917 | -19.7430 | .0000 |
| Fabricating | -16293.3562 | -1.6955 | .0000 |
| Machinery | 711.9905 | -10.1016 | .0000 |
| Transportation | | | |
| Equipment | -120.0924 | 12.7098 | .0000 |
| Electrical | | | |
| Products | -9.0801 | .2419 | .0000 |
| Non-metallic | | | |
| Minerals | -1.2079 | -9.6816 | .0000 |
| Chemical and | | | |
| Chemical Products | -34.2115 | -17.4952 | .0000 |

CHAPTER 7 CONCLUSION AND SUMMARY

Overall the results of this were in line with the literature cited in chapter 3. As with other work this study did not conform very well with economic theory. For the energy submodel the own price elasticities were not all negative in 9 of the 11 industries. These results are in line with those reported by Fuss, who finds that not all of the own price elasticities are negative and that there is a high degree of interfuel substitution. The model did however have a reasonably good fit with high R^2 's and good t statistics.

For the AES's in the energy submodel 196 of the 330 price elasticities are positive indicating only a moderate degree of substitutability among fuels. This is important when governments are considering such things as increasing a fuel tax to raise revenue or curtail pollution. In the former case revenues will increase due to the inability of the producer to substitute one fuel for another. In the latter case pollutants may not decline for the same reason.

The Static model did not perform very well in the sense that homogeneity and symmetry are rejected in 10 of the 11 industries. I cannot compare this to the studies of Berndt and Wood and Fuss because they assume homogeneity and symmetry. For the static model to reject symmetry conditions is not unusual as Anderson and Blundell note. Otherwise the AES's

did not conform with economic theory in that in only 4 of the 11 industries were all of the own price elasticities negative. For the overall fit of the model the low Durbin Watsons suggested that a dynamic model might be in order.

In the static model the substitutability patterns for capital and energy and capital and labour were in agreement with Gregory and Griffon who suggested that they were both substitutes. This implies that increasing such things as the marginal corporate tax rate, which would result in a higher price of capital, would result in increase usage of labour and energy. Energy and labour are for the most parts complements which is in direct disagreement with the results of Gregory and Griffon and Berndt and Wood. This implies that an increase in the price of energy would result in less usage of labour.

The Dynamic model was accepted over the static, partial adjustment, and autoregressive models in 9 of the 11 industries while in the other 2 the autoregressive model is accepted. In only 2 of the 11 industries is the cost function homogeneous and in none of them is the function homogeneous and symmetric. For the dynamic model the results are in line with Anderson and Blundell and Friesen who both reject symmetry conditions. Otherwise in 7 of the industries the own price elasticities are all negative which is in agreement with economic theory.

As far as policy implications go capital and labour are

for the most part substitutes so that any action on the government's behave to increase the firm's user cost of capital would result in more usage of labour. Capital and energy are also substitutes so an increase in energy prices would result in the firm substituting capital for labour. Again in the dynamic model labour and energy are complements so an increase in the price of energy would result in less usage of labour. This may partly explain what happened in the two oil shocks of the 1970's and 1980's as firms were unable to substitute labour for energy and people became unemployed.

Finally an area of future research might be to examine the autoregressive, partial adjustment, and dynamic model for the energy submodel rather than just the static. Furthermore the dynamic model as presented by Anderson and Blundell is ad hoc in the sense that it is not the result of any optimization process that the firm undertakes. An area of future research could be to derive an explicit economic optimization process the solution to which results in the dynamic model.

Appendix A Data Construction and Sources

p_1 : Price of gasoline. Source "Consumption of Purchased Fuels and Electricity."

p_2 : Price of fuel oil. Source "Consumption of Purchased Fuels and Electricity."

p_3 : Price of electricity. Source "Consumption of Purchased Fuels and Electricity."

p_4 : Price of coal and coke. Source "Consumption of Purchased Fuels and Electricity."

p_5 : Price of natural gas. Source "Consumption of Purchased Fuels and Electricity."

p_6 : Price of liquid petroleum gas. Source "Consumption of Purchased Fuels and Electricity."

$$p_K = p (r + (1 - \tau) + \delta - \Delta p) / (1 - \tau)$$

where

p : Cost of capital index. Source Fixed Capital Flows and Stocks.

r : Long term bond rate. Source CANSIM.

τ : Effective marginal corporate tax rate. Source "Real Effective Corporate Tax Rates in Canada and the United States after tax Reform"

δ : Long term depreciation rate assumed to be .10.

Δp : Cost of capital inflation rate, generated for p .

p_L : Average hourly wage rate. Source "Manufacturing Industries of Canada."

p_E : Price of energy, generated from p_1 to p_6 .

Q: Manufacturing Shipments. Source "Manufacturing Industries of Canada."

Total Cost = cost of energy + capital cost + wages.

Where the cost of energy is from "Consumption of Purchased Fuels and Electricity." Capital cost is from "Fixed Capital Flows and Stocks." And Wages is from "Manufacturing Industries in Canada."

Energy Cost = cost of gas + ... + cost of liquid petroleum gas.

Where these costs are derived from "Consumption of Purchased Fuels and Electricity."

$S_1 = p_1 Q_1 / \text{Energy cost}$

where Q_1 is the quantity of the energy component and is derived from the "Consumption of Purchased Fuels and Electricity".

SK = Cost of Capital / Total Cost

SL = Cost of Labour / Total Cost

SE = Cost of Energy / Total Cost

Appendix B The Empirical Results for the Energy Submodel

Table B.1 Rubber and Plastic Products (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R ² | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------|------|
| 1 | .02600 (.0026) | .00860 (.0128) | .02673 (.0065) | .00423 (.0067) | .00910 (.0049) | -.04327 (.0090) | -.00539 (-----) | .5522 | 1.46 |
| 2 | .59584 (.0098) | .02673 (.0065) | .31321 (.0102) | -.02719 (.0106) | -.02320 (.0112) | -.33767 (.0138) | .04812 (-----) | .9147 | 1.48 |
| 3 | .18082 (.0123) | .00423 (.0065) | -.02719 (.0106) | -.26163 (.0084) | -.02625 (.0105) | .25682 (.0274) | .05003 (-----) | .3485 | 1.02 |
| 4 | .09245 (.0105) | .00910 (.0049) | -.02320 (.0112) | -.02625 (.0105) | -.13037 (.0145) | .07017 (.0137) | .10055 (-----) | .6056 | .77 |
| 5 | .09778 (.0110) | -.04327 (.0090) | -.33767 (.0138) | .25682 (.0274) | .07017 (.0137) | -.06485 (.0331) | .11880 (-----) | .9672 | 1.32 |
| 6 | .00711 (-----) | -.00539 (-----) | .04812 (-----) | .05003 (-----) | .10055 (-----) | .11880 (-----) | -.31211 (-----) | | |

Table B.2 Wood Industry (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R ² | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|----------------|------|
| 1 | .47265 (.0189) | -.24754 (.1713) | .44490 (.0202) | -.14003 (.0229) | -.02649 (.0293) | -.00207 (.1400) | -.02877 (----) | .9540 | 1.17 |
| 2 | .00758 (.0759) | .44490 (.0202) | -.44055 (.0233) | .16638 (.0420) | -.00458 (.0041) | -.26705 (.0251) | .10090 (----) | .9322 | .67 |
| 3 | .36692 (.0308) | -.14003 (.0229) | .16638 (.0420) | .15730 (.1166) | .04645 (.0126) | -.07559 (.1046) | -.15451 (----) | .7171 | 1.17 |
| 4 | .02472 (.0035) | -.02649 (.0293) | -.00458 (.0041) | .04645 (.0126) | -.00744 (.0086) | -.01295 (.0231) | .00501 (----) | .6179 | 1.15 |
| 5 | .08703 (.0249) | -.00207 (.1400) | -.26705 (.0251) | -.07559 (.1046) | -.01295 (.0231) | .28334 (.0866) | .07432 (----) | .9248 | .61 |
| 6 | .04110 (----) | -.02877 (----) | .10090 (----) | -.15451 (----) | .00501 (----) | .07432 (----) | .00305 (----) | | |

Table B.3 Furniture and Fixtures Industry (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R^2 | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------|------|
| 1 | .16710 (.0034) | -.05029 (.0097) | .06779 (.0069) | -.01277 (.0085) | -.06485 (.0091) | -.05960 (.0096) | .11972 (----) | .9786 | 2.05 |
| 2 | .52303 (.0057) | .06779 (.0069) | .18164 (.0050) | -.05096 (.0084) | -.00004 (.0053) | -.19911 (.0109) | .00068 (----) | .9489 | 1.62 |
| 3 | .16110 (.0126) | -.01277 (.0085) | -.05096 (.0084) | -.60006 (.0128) | -.02194 (.0104) | .12735 (.0142) | .55838 (----) | .0258 | .45 |
| 4 | .07399 (.0047) | -.06485 (.0091) | -.00004 (.0053) | -.02194 (.0104) | -.02826 (.0102) | .12507 (.0090) | -.00998 (----) | .7923 | 1.23 |
| 5 | .07046 (.0127) | -.05960 (.0096) | -.19911 (.0109) | .12735 (.0142) | .12507 (.0090) | -.10041 (.0324) | .10670 (----) | .9424 | .50 |
| 6 | -.00068 (----) | .11972 (----) | .00068 (----) | .55838 (----) | -.00998 (----) | .10670 (----) | -.77550 (----) | | |

Table B.4 Paper and Allied Industries (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R^2 | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------|------|
| 1 | .00798 (.0008) | .00784 (.0022) | -.00743 (.0057) | .00483 (.0028) | .00902 (.0029) | -.01527 (.0081) | .00101 (----) | .7286 | 1.17 |
| 2 | .46763 (.0060) | -.00784 (.0344) | .24138 (.0191) | -.06686 (.0178) | -.05421 (.0571) | -.11909 (.0146) | .00662 (----) | .9255 | 2.02 |
| 3 | .26785 (.1460) | .00483 (.0028) | -.06686 (.0178) | -.38346 (.0495) | -.02234 (.0330) | .46392 (.0158) | .00391 (----) | .4099 | 1.42 |
| 4 | .11575 (.0109) | .00902 (.0029) | -.05421 (.0571) | -.02234 (.0330) | -.22173 (.0299) | .29048 (.0441) | -.00122 (----) | .6056 | .77 |
| 5 | .13620 (.0159) | -.01527 (.0081) | -.11909 (.0146) | .46392 (.0158) | .29048 (.0441) | -.60810 (.0792) | -.14814 (----) | .9672 | 1.32 |
| 6 | .00459 (----) | .00101 (----) | .00662 (----) | .00391 (----) | -.00122 (----) | -.14814 (----) | .13782 (----) | | |

Table B.5 Primary Minerals (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R ² | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|------------------|----------------|------|
| 1 | .00890 (.0008) | .01159 (.0015) | -.00717 (.0014) | -.00196 (.0020) | .00639 (.0023) | -.01146 (.0031) | .00261 (----) | .9914 | .99 |
| 2 | .53566 (.0060) | -.00717 (.0344) | .27651 (.0191) | -.09004 (.0178) | .03759 (.0571) | -.22093 (.0146) | .00404 (----) | .7646 | 1.05 |
| 3 | .16782 (.0212) | -.00196 (.0020) | -.09004 (.0178) | -.05927 (.0601) | -.08977 (.0224) | .23858 (.0275) | .00246 (----) | .0153 | .40 |
| 4 | .13279 (.0109) | .00639 (.0023) | .03759 (.0571) | -.08977 (.0224) | -.19580 (.0356) | .14590 (.0387) | .09569 (----) | .5443 | .88 |
| 5 | .14590 (.0026) | -.01146 (.0031) | -.22093 (.0146) | .23858 (.0275) | .14590 (.0387) | -.22949 (.0366) | .07740 (----) | .6197 | .60 |
| 6 | .00893 (----) | .00261 (----) | .00404 (----) | .00246 (----) | .09569 (----) | .07740 (----) | .18220 (----) | | |

Table B.6 Metal Fabricating Industry (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R^2 | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------|------|
| 1 | .12455 (.0031) | .00923 (.0171) | .09788 (.0103) | -.03195 (.0171) | -.03918 (.0102) | -.01286 (.0225) | -.02312 (----) | .9777 | 1.62 |
| 2 | .45194 (.0060) | .09788 (.0103) | .11389 (.0106) | -.02003 (.0202) | -.01166 (.0070) | -.20088 (.0193) | -.43489 (----) | .8455 | 1.27 |
| 3 | .14615 (.0145) | -.03195 (.0171) | -.02003 (.0202) | -.09173 (.0423) | .21732 (.0152) | .11756 (.0534) | -.19117 (----) | .0540 | 1.12 |
| 4 | .02284 (.0028) | -.03918 (.0102) | -.01166 (.0070) | .21732 (.0152) | -.03210 (.0082) | .05996 (.0169) | -.19434 (----) | .5711 | 1.07 |
| 5 | .23439 (.0107) | -.01286 (.0225) | -.20088 (.0193) | .11756 (.0534) | .05996 (.0169) | .05791 (.0479) | -.02169 (----) | .9095 | .93 |
| 6 | .02013 (----) | -.02312 (----) | -.43489 (----) | -.19117 (----) | -.19434 (----) | -.02169 (----) | .86521 (----) | | |

Table B.7 Transportation Equipment (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R ² | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|----------------|------|
| 1 | .08450 (.0041) | .00437 (.0646) | .00885 (.0222) | .01882 (.0775) | -.07108 (.0772) | .03854 (.1040) | .00050 (----) | .8960 | 1.19 |
| 2 | .45276 (.0093) | .00885 (.0222) | .23515 (.0703) | -.04487 (.1130) | .01498 (.0691) | -.20801 (.1426) | -.00610 (----) | .8955 | 1.29 |
| 3 | .15265 (.0432) | .01882 (.0775) | -.04487 (.1130) | .02085 (.1337) | -.04016 (.0569) | .03517 (.2996) | .01019 (----) | .0853 | .68 |
| 4 | .16760 (.0088) | -.07108 (.0772) | -.01498 (.0691) | .04016 (.0569) | -.07874 (.0670) | .16302 (.1630) | -.03838 (----) | .8999 | .69 |
| 5 | .12747 (.0100) | .03854 (.0192) | -.20801 (.0138) | .03517 (.0219) | .16302 (.0105) | -.06986 (.0361) | .04114 (----) | .9213 | .47 |
| 6 | .01502 (----) | .00050 (----) | -.00610 (----) | .01019 (----) | -.03838 (----) | .04114 (----) | -.00735 (----) | | |

Table B.8 Machinery Industry (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R ² | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|----------------|------|
| 1 | .08974 (.0033) | .00800 (.0169) | .07379 (.0082) | .00273 (.0103) | -.02923 (.0078) | -.03829 (.0192) | -.01700 (-----) | .9492 | 2.69 |
| 2 | .53398 (.0065) | .07379 (.0082) | .17293 (.0108) | -.02543 (.0118) | -.03063 (.0071) | -.20608 (.0138) | .01542 (-----) | .8975 | 1.72 |
| 3 | .14131 (.0107) | .00273 (.0103) | .02543 (.0118) | -.08825 (.0259) | .01566 (.0097) | .08774 (.0219) | -.04331 (-----) | .0853 | .68 |
| 4 | .03981 (.0030) | -.02923 (.0078) | -.03063 (.0071) | .01566 (.0097) | -.07352 (.0067) | .11854 (.0105) | -.00082 (-----) | .9072 | .48 |
| 5 | .17799 (.0100) | -.03829 (.0192) | -.20608 (.0138) | .08774 (.0219) | .11854 (.0105) | .06024 (.0361) | -.02215 (-----) | .9095 | .93 |
| 6 | .01717 (-----) | -.01700 (-----) | .01542 (-----) | -.04331 (-----) | -.00082 (-----) | -.02215 (-----) | .06786 (-----) | | |

Table B.9 Electrical Products (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R^2 | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------|------|
| 1 | .04331 (.0008) | .02117 (.0034) | .01087 (.0017) | -.01666 (.0017) | -.01747 (.0013) | .07166 (.0040) | -.11288 (----) | .9830 | 2.05 |
| 2 | .55564 (.0064) | .01087 (.0017) | .32841 (.0071) | -.09556 (.0037) | -.04256 (.0034) | -.21743 (.0034) | -.53937 (----) | .8975 | 1.72 |
| 3 | .18824 (.0111) | -.01666 (.0017) | -.09556 (.0037) | -.07089 (.0043) | .00463 (.0035) | .17623 (.0025) | -.18599 (----) | .0853 | .68 |
| 4 | .07151 (.0026) | -.01747 (.0013) | -.04256 (.0034) | .00463 (.0035) | -.06115 (.0031) | .12555 (.0030) | -.08051 (----) | .9072 | .48 |
| 5 | .12462 (.0093) | .07166 (.0040) | -.21743 (.0034) | .17623 (.0025) | .12555 (.0030) | -.07593 (.0094) | -.20470 (----) | .9095 | .93 |
| 6 | .01668 (----) | -.11288 (----) | -.53937 (----) | -.18599 (----) | -.08051 (----) | -.20470 (----) | 1.12345 (----) | ---- | -- |

Table B.10 Non-metallic Mineral Products Industry (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R ² | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|----------------|------|
| 1 | .09676 (.0026) | -.00442 (.0180) | .08466 (.0114) | -.02603 (.0133) | -.07502 (.0123) | .03289 (.0217) | -.01208 (----) | .9830 | 2.05 |
| 2 | .32014 (.0084) | .08466 (.0114) | -.01323 (.0248) | .12158 (.0341) | .13584 (.0238) | -.32015 (.0328) | -.00870 (----) | .8975 | 1.72 |
| 3 | .21757 (.0136) | -.02603 (.0133) | .12158 (.0341) | -.22751 (.0736) | .06838 (.0428) | .06930 (.0276) | -.00572 (----) | .0853 | .68 |
| 4 | .13355 (.0102) | -.07502 (.0123) | .13584 (.0238) | .06838 (.0428) | -.19294 (.0366) | .07615 (.0182) | .06810 (----) | .9072 | .48 |
| 5 | .22502 (.0126) | .03289 (.0217) | -.32015 (.0328) | .06930 (.0276) | .07615 (.0182) | .11562 (.0433) | .02619 (----) | .9095 | .93 |
| 6 | .00696 (----) | -.01208 (----) | -.00870 (----) | -.00572 (----) | .06810 (----) | .02619 (----) | -.06779 (----) | ---- | -- |

Table B.11 Chemical and Chemical Products (standard errors in parenthesis)

| eq | α_1 | β_{11} | β_{12} | β_{13} | β_{14} | β_{15} | β_{16} | R ² | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|----------------|------|
| 1 | .02156 (.0006) | .00658 (.0022) | -.00234 (.0029) | -.01151 (.0019) | -.00728 (.0019) | .00879 (.0039) | .00576 (----) | .9830 | 2.05 |
| 2 | .56263 (.0077) | -.00234 (.0029) | .26350 (.0139) | -.02942 (.0062) | .04872 (.0074) | -.29765 (.0136) | .01719 (----) | .8975 | 1.72 |
| 3 | .09407 (.0138) | -.01151 (.0019) | -.02942 (.0062) | -.21218 (.0065) | .04091 (.0072) | .28512 (.0071) | -.07292 (----) | .0853 | .68 |
| 4 | .10981 (.0093) | -.00728 (.0019) | .04872 (.0074) | .04091 (.0072) | -.28191 (.0202) | .25359 (.0203) | -.05403 (----) | .9072 | .48 |
| x | | | | | | | | | |
| 5 | .19903 (.0110) | .00879 (.0039) | -.29765 (.0136) | .28512 (.0071) | .25359 (.0203) | -.19430 (.0295) | -.05555 (----) | .9095 | .93 |
| 6 | .01290 (----) | .00576 (----) | .01719 (----) | -.07292 (----) | -.05403 (----) | -.05555 (----) | .15955 (----) | ---- | -- |

Appendix C AES's for the Energy Submodel

Table C.1 Fuel Types

| Number | Fuel Type |
|--------|----------------------|
| 1 | Gasoline |
| 2 | Fuel Oil |
| 3 | Electricity |
| 4 | Coal and Coke |
| 5 | Natural Gas |
| 6 | Liquid Petroleum Gas |

Table C.2 AES for the Rubber and Plastics Industry:

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | 189.51 | 3.95 | 2.10 | 13.95 | -7.95 | -847.21 |
| 2 | 3.95 | .277 | .721 | 2.30 | -1.75 | 1.69 |
| 3 | 2.10 | .721 | -10.20 | 4.45 | 5.92 | 2.44 |
| 4 | 13.95 | 2.30 | 4.45 | -119.93 | 8.36 | 9.55 |
| 5 | -7.95 | -1.75 | 5.92 | 8.36 | -1.91 | -7.22 |
| 6 | -847.21 | 1.69 | 2.44 | 9.55 | -7.22 | 3126.25 |

Table C.3 AES for the Wood Industry:

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -475.81 | 110.00 | -21.82 | -11.77 | .701 | -6.12 |
| 2 | 110.00 | -19.89 | 4.78 | .692 | -4.35 | 4.48 |
| 3 | -21.82 | 4.78 | -.509 | 3.07 | -.007 | -2.54 |
| 4 | -11.77 | .692 | 3.07 | -11.48 | .489 | 1.34 |
| 5 | .701 | -4.35 | -.007 | .489 | .901 | 2.50 |
| 6 | -6.12 | 4.48 | -2.54 | 1.34 | 2.50 | -4.80 |

Table C.4 AES for the Furniture and Fixtures Industry:

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -19.33 | 2.85 | -.087 | -30.40 | 3.60 | 2.31 |
| 2 | 2.85 | -.318 | .239 | .996 | -.525 | 1.29 |
| 3 | -.087 | .239 | -8.60 | -4.80 | 4.03 | 26.01 |
| 4 | -30.40 | .996 | -4.80 | -80.26 | 17.97 | -76.39 |
| 5 | 3.60 | -.525 | 4.03 | 17.97 | -3.73 | -7.76 |
| 6 | 2.31 | 1.29 | 26.01 | -76.39 | -7.76 | -81.12 |

Table C.5 AES for the Paper and Allied Industry:

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -22.61 | -.616 | 3.10 | 16.29 | -4.56 | 21.24 |
| 2 | -.616 | -.027 | .316 | -1.15 | .018 | 3.89 |
| 3 | 3.10 | .316 | -11.35 | -.778 | 8.93 | 4.64 |
| 4 | 16.29 | -1.15 | -.778 | -85.39 | 20.35 | -3.40 |
| 5 | -4.56 | .018 | 8.93 | 20.35 | -11.48 | -8.33 |
| 6 | 21.24 | 3.89 | 4.64 | -3.40 | -8.33 | -119.59 |

Table C.6 AES for the Primary Metals:

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | 6.11 | -.502 | .0001 | 8.51 | -2.58 | 34.11 |
| 2 | -.502 | .162 | -.162 | 2.11 | -.743 | 2.31 |
| 3 | .0001 | -.162 | -6.47 | -5.50 | 5.59 | 2.92 |
| 4 | 8.51 | 2.11 | -5.50 | -44.62 | 11.58 | 6.27 |
| 5 | -2.58 | -.743 | 5.59 | 11.58 | -5.12 | -6.38 |
| 6 | 34.11 | 2.31 | 2.92 | 6.27 | -6.38 | -73.67 |

Table C.7 AES for the Metal Fabricating Industry

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -11.06 | 4.21 | -2.18 | -52.89 | .486 | -26.92 |
| 2 | 4.21 | -.733 | .657 | -1.75 | -.377 | 5.31 |
| 3 | -2.18 | .657 | -10.95 | 16.56 | 3.44 | 3.77 |
| 4 | -52.89 | -1.75 | 16.56 | -416.28 | 18.22 | 11.85 |
| 5 | .486 | -.377 | 3.44 | 18.22 | -1.38 | -4.92 |
| 6 | -26.93 | 5.31 | 3.77 | 11.85 | -4.92 | 67.41 |

Table C.8 AES for the Machinery Industry

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -16.16 | 4.43 | 1.32 | -22.39 | -1.40 | -38.88 |
| 2 | 4.43 | -.378 | .611 | -1.70 | -.426 | 5.07 |
| 3 | 1.32 | .611 | -9.73 | 5.10 | 2.80 | 7.21 |
| 4 | -22.39 | -1.70 | 5.10 | -149.37 | 15.08 | -2.68 |
| 5 | -1.40 | -.426 | 2.80 | 15.08 | -1.49 | -6.88 |
| 6 | -38.88 | 5.07 | 7.21 | -2.68 | -6.88 | 105.82 |

Table C.9 AES for the Transportation Equipment

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -19.44 | 1.45 | 3.93 | -23.13 | 3.93 | 2.35 |
| 2 | 1.45 | -.057 | .294 | 1.51 | -.597 | -.632 |
| 3 | 3.93 | .294 | -4.89 | -3.13 | 1.81 | 9.23 |
| 4 | -23.13 | 1.51 | -3.13 | -31.58 | 10.84 | -35.65 |
| 5 | 3.93 | -.597 | 1.81 | 10.84 | -3.14 | 4.25 |
| 6 | 2.35 | -.632 | 9.23 | -35.65 | 4.25 | -6.16 |

Table C.10 AES for the Electrical Products Industry

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -8.07 | 1.77 | -2.77 | -24.26 | 24.62 | .396 |
| 2 | 1.77 | .329 | -.268 | -2.60 | -40.97 | 1.11 |
| 3 | -2.77 | -.268 | -8.45 | 2.23 | 108.89 | 1.03 |
| 4 | -24.26 | -2.60 | 2.23 | -144.83 | 490.13 | -.265 |
| 5 | 24.62 | -40.97 | 108.89 | 490.13 | -767.63 | -4.15 |
| 6 | .396 | 1.11 | 1.03 | -.265 | -4.15 | -2.26 |

Table C.11 AES for Non-metallic Mineral Products Industry

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -18.76 | 5.52 | -1.53 | -1.12 | 2.74 | 1.38 |
| 2 | 5.52 | -2.03 | 2.88 | 1.61 | -1.71 | 1.04 |
| 3 | -1.53 | 2.88 | -10.74 | 1.56 | 2.06 | 1.05 |
| 4 | -1.12 | 1.61 | 1.56 | -1.01 | 1.32 | 1.02 |
| 5 | 2.74 | -1.71 | 2.06 | 1.32 | -.926 | .845 |
| 6 | 1.38 | 1.04 | 1.05 | 1.02 | .845 | 2.75 |

Table C.12 AES for Chemical and Chemical Products Industry

| equation | σ_{11} | σ_{12} | σ_{13} | σ_{14} | σ_{15} | σ_{16} |
|----------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1 | -33.87 | .725 | -3.11 | .249 | 2.55 | .328 |
| 2 | .725 | .069 | .581 | 1.20 | -1.09 | .920 |
| 3 | -3.11 | .581 | -14.81 | .486 | 1.61 | -2.76 |
| 4 | .249 | 1.20 | .486 | -1.92 | 2.57 | .886 |
| 5 | 2.55 | -1.09 | 1.61 | 2.57 | -4.32 | -.408 |
| 6 | .328 | .920 | -2.76 | .886 | -.408 | .760 |

Appendix D Price Elasticities for the Energy Submodel

Table D.1 : Price Elasticities for the Rubber and Plastics Industry:

| fuel | Ei1 | Ei2 | Ei3 | Ei4 | Ei5 | Ei6 |
|------|-------|-------|-------|-------|-------|-------|
| 1 | 3.57 | 1.89 | .428 | .519 | -2.03 | -4.38 |
| 2 | .074 | .132 | .146 | .085 | -.448 | .008 |
| 3 | .039 | .345 | -2.08 | .166 | 1.51 | .012 |
| 4 | .263 | 1.10 | .06 | -4.46 | 2.14 | .049 |
| 5 | -8.34 | -.840 | 1.20 | .311 | -.490 | -.037 |
| 6 | -1.02 | .810 | .497 | .354 | -.849 | 1.21 |

Table D.2 : Price Elasticities for the Wood Industry:

| fuel | Ei1 | Ei2 | Ei3 | Ei4 | Ei5 | Ei6 |
|------|--------|-------|-------|-------|-------|-------|
| 1 | -11.35 | 18.81 | -5.61 | -1.02 | .204 | -1.03 |
| 2 | 2.62 | -3.40 | 1.22 | .060 | -1.26 | .759 |
| 3 | -.520 | .818 | -.131 | .267 | -.002 | -.431 |
| 4 | -.280 | .118 | .791 | -.998 | .142 | .227 |
| 5 | .016 | -.744 | -.001 | .042 | .263 | .424 |
| 6 | -.146 | .767 | -.655 | .116 | .730 | -.813 |

Table D.3 Price Elasticities for the Furniture and Fixtures Industry.

| fuel | Ei1 | Ei2 | Ei3 | Ei4 | Ei5 | Ei6 |
|------|-------|-------|-------|-------|-------|-------|
| 1 | -1.54 | 1.30 | -.012 | -.784 | 1.03 | .011 |
| 2 | .228 | -.145 | .035 | .025 | -.150 | .006 |
| 3 | -.007 | .109 | -1.26 | -.123 | 1.15 | .129 |
| 4 | -2.43 | .455 | -.704 | -2.07 | 5.13 | -.381 |
| 5 | .288 | -.240 | .592 | .463 | -1.06 | -.038 |
| 6 | .185 | .590 | 3.81 | -1.97 | -2.21 | -.405 |

Table D.4 Price Elasticities for the Paper and Allied Industry.

| fuel | Ei1 | Ei2 | Ei3 | Ei4 | Ei5 | Ei6 |
|------|-------|-------|-------|-------|-------|-------|
| 1 | -.234 | -.272 | .686 | .924 | -1.20 | .102 |
| 2 | -.006 | -.011 | .070 | -.657 | -.004 | .018 |
| 3 | .032 | .140 | -2.51 | -.044 | 2.36 | .022 |
| 4 | .169 | -.512 | -.172 | -4.84 | 5.38 | -.016 |
| 5 | -.047 | -.008 | 1.97 | 1.15 | -3.03 | -.040 |
| 6 | .220 | 1.72 | 1.02 | -.193 | -2.20 | -.578 |

Table D.5 Price Elasticities for the Primary Metals Industry.

| <u>fuel</u> | <u>Ei1</u> | <u>Ei2</u> | <u>Ei3</u> | <u>Ei4</u> | <u>Ei5</u> | <u>Ei6</u> |
|-------------|------------|------------|------------|------------|------------|------------|
| 1 | .067 | -.218 | 2.59 | .659 | -.752 | .244 |
| 2 | -.005 | .070 | -.028 | .163 | -.216 | .016 |
| 3 | .000001 | -.070 | -1.15 | -.426 | 1.63 | .020 |
| 4 | .093 | .919 | -.981 | -3.45 | 3.37 | .044 |
| 5 | -.028 | -.323 | .996 | .896 | -1.49 | -.045 |
| 6 | .374 | 1.00 | .521 | .485 | -1.86 | -.527 |

Table D.6 Price Elasticities for the Metal Fabricating Industry.

| <u>fuel</u> | <u>Ei1</u> | <u>Ei2</u> | <u>Ei3</u> | <u>Ei4</u> | <u>Ei5</u> | <u>Ei6</u> |
|-------------|------------|------------|------------|------------|------------|------------|
| 1 | -.799 | 1.77 | -.302 | -.531 | .168 | -.308 |
| 2 | .304 | -.308 | .091 | -.017 | -.130 | .060 |
| 3 | -.157 | .276 | -1.52 | .166 | -.157 | .043 |
| 4 | -3.82 | -.738 | 2.30 | -4.18 | 6.31 | .135 |
| 5 | .035 | -.159 | .478 | .183 | -.481 | -.056 |
| 6 | -1.94 | 2.23 | .524 | .119 | -1.70 | .771 |

Table D.7 Price Elasticities for the Machinery Industry.

| <u>fuel</u> | <u>Ei1</u> | <u>Ei2</u> | <u>Ei3</u> | <u>Ei4</u> | <u>Ei5</u> | <u>Ei6</u> |
|-------------|------------|------------|------------|------------|------------|------------|
| 1 | -.786 | 1.95 | .197 | -.575 | -.459 | -.333 |
| 2 | .216 | -.166 | .090 | -.043 | -.139 | .043 |
| 3 | .064 | .269 | -1.44 | .131 | .918 | .061 |
| 4 | -1.08 | -.751 | .758 | -3.83 | 4.94 | -.023 |
| 5 | -.068 | -.188 | .416 | .387 | -.488 | -.058 |
| 6 | -1.89 | 2.23 | 1.07 | -.068 | -2.25 | .906 |

Table D.8 Price Elasticities for the Transportation Equipment Industry.

| <u>fuel</u> | <u>Ei1</u> | <u>Ei2</u> | <u>Ei3</u> | <u>Ei4</u> | <u>Ei5</u> | <u>Ei6</u> |
|-------------|------------|------------|------------|------------|------------|------------|
| 1 | -.856 | .638 | .572 | -1.54 | 1.17 | .020 |
| 2 | .064 | -.025 | .042 | .101 | -.177 | -.005 |
| 3 | .173 | .128 | -.711 | -.209 | .539 | .078 |
| 4 | -1.01 | .661 | -.455 | -2.11 | 3.22 | -.304 |
| 5 | .173 | -.261 | .263 | .725 | -.937 | .036 |
| 6 | .103 | -.276 | 1.34 | -2.38 | 1.26 | -.052 |

Table D.9 Price Elasticities for the Electrical Products Industry.

| fuel | Ei1 | Ei2 | Ei3 | Ei4 | Ei5 | Ei6 |
|------|-------|--------|-------|-------|-------|-------|
| 1 | -.230 | .868 | -.428 | -.586 | .261 | .116 |
| 2 | .050 | .160 | -.041 | -.062 | -.434 | .327 |
| 3 | -.079 | -.130 | -1.30 | .054 | 1.15 | .305 |
| 4 | -.693 | -1.27 | .345 | -3.50 | 5.20 | -.077 |
| 5 | .703 | -20.00 | 16.80 | 11.85 | -8.14 | -1.22 |
| 6 | .011 | .543 | .160 | -.006 | -.044 | -.664 |

Table D.10 Price Elasticities for the Non-metallic Mineral Products Industry.

| fuel | Ei1 | Ei2 | Ei3 | Ei4 | Ei5 | Ei6 |
|------|-------|-------|-------|-------|-------|-------|
| 1 | -1.02 | 1.89 | -.287 | -1.30 | .946 | -.215 |
| 2 | .302 | -.696 | .543 | .461 | -.590 | -.019 |
| 3 | -.083 | .988 | -2.02 | .427 | .713 | -.024 |
| 4 | -1.10 | 2.44 | 1.24 | -3.92 | 1.52 | -.186 |
| 5 | .149 | -.585 | .388 | .285 | -.319 | -.081 |
| 6 | -2.14 | -1.24 | -.853 | -2.19 | 5.12 | 1.31 |

Table D.11 Price Elasticities for the Chemical and Chemical Products Industry.

| fuel | Ei1 | Ei2 | Ei3 | Ei4 | Ei5 | Ei6 |
|------|-------|-------|-------|-------|-------|-------|
| 1 | -.625 | .336 | -.472 | -.341 | .783 | .319 |
| 2 | .013 | .032 | .088 | .157 | -.336 | .044 |
| 3 | -.057 | .269 | -2.24 | -.223 | 2.18 | .072 |
| 4 | -.120 | 1.39 | -.645 | -6.31 | 5.13 | .555 |
| 5 | .047 | -.507 | 1.08 | .879 | -1.33 | -.170 |
| 6 | .744 | 2.71 | 1.45 | 3.83 | -6.85 | -1.92 |

Appendix E Empirical Results for the Static Model

Table E.1 Parameter Estimates for the Static Model for the Rubber and Plastics Industry

| eq | α_1 | β_{1K} | β_{1L} | β_{1E} | β_{1T} | β_{1Q} | R^2 | DW |
|----|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------|------|
| K | 3.7030 (.2979) | .02466 (.0300) | .08438 (.0223) | -.29864 (.0654) | .02468 (.0156) | -.14840 (.0054) | .9522 | 2.26 |
| E | -1.6363 (.2565) | -.06774 (.0263) | -.03232 (.0190) | .46947 (.0568) | -.03276 (.0134) | .08642 (.0047) | .9775 | 1.87 |

Table E.2 Parameter Estimates for the Static Model for the Wood Industry

| eq | α_1 | β_{1K} | β_{1L} | β_{1E} | β_{1T} | β_{1Q} | R^2 | DW |
|----|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|-------|------|
| K | 2.5586 (.3643) | .01185 (.0125) | -.03935 (.0241) | -.00827 (.0460) | .01155 (.0174) | -.08899 (.0044) | .7123 | .80 |
| E | .29262 (.2457) | .01187 (.0084) | .00868 (.0160) | .14532 (.0308) | -.01115 (.0029) | -.01253 (.0117) | .9608 | 1.69 |

Table E.3 Parameter Estimates for the Static Model for the Furniture and Fixtures Industry

| eq | α_i | β_{iK} | β_{iL} | β_{iE} | β_{iI} | β_{iQ} | R^2 | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------|------|
| K | .16515 (.3643) | .02413 (.0125) | -.00508 (.0241) | -.68889 (.0460) | .042024 (.0174) | .18961 (.0044) | .9689 | 1.40 |
| E | 4.4461 (.2457) | -.05394 (.0084) | .01700 (.0160) | 1.2806 (.0308) | -.06433 (.0029) | -.21757 (.0117) | .9813 | 1.44 |

Table E.4 Parameter Estimates for the Static Model for the Paper and Allied Industry⁴⁹

| eq | α_i | β_{iK} | β_{iL} | β_{iE} | β_{iI} | β_{iQ} | R^2 | DW |
|----|-------------------|-------------------|------------------|--------------------|--------------------|--------------------|-------|------|
| K | 2.2814 (2.062) | -.0113 (.0176) | ----- (-----) | ----- (-----) | .00476 (.0019) | -.06750 (.0208) | .7395 | 1.10 |
| E | -.4255 (.3591) | .03705 (.0092) | ----- (-----) | -.00212 (.0087) | -.00166 (.0019) | .21834 (.0020) | .3276 | .68 |

⁴⁹ Homogeneity and symmetry imposed.

table E.5 Parameter Estimates for the Static Model for the Primary Metals Industry⁵⁰

| eq | α_1 | β_{Ik} | β_{Il} | β_{Ie} | β_{It} | β_{Iq} | R^2 | DW |
|----|-------------------|-------------------|--------------------|--------------------|-------------------|-------------------|-------|------|
| K | .8716 (.0030) | -.0318 (.0093) | .0587 (.0144) | -.01484 (.0073) | ----- (.-----) | ----- (.-----) | .7918 | 1.48 |
| E | -.0278 (.0020) | .02269 (.0061) | -.03779 (.0096) | -.01579 (.0073) | ----- (.-----) | ----- (.-----) | .4922 | .73 |

Table E.6 Parameter Estimates for the Static Model for the Metal Fabricating Industry

| eq | α_1 | β_{Ik} | β_{Il} | β_{Ie} | β_{It} | β_{Iq} | R^2 | DW |
|----|-------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------|------|
| K | 3.3100 (.6610) | -.01412 (.0040) | .06052 (.0574) | -.01412 (.0133) | .01146 (.0040) | -.1222 (.0359) | .9226 | 1.57 |
| E | -.5233 (.6610) | -.08808 (.0360) | -.06052 (.0574) | .01446 (.0133) | -.01591 (.0035) | .02686 (.0311) | .9659 | 1.60 |

⁵⁰ Hicks Neutral Technological Change and homotheticity.

Table E.7 Parameter Estimates for the Static Model for the Machinery Industry

| eq | α_1 | β_{Ik} | β_{Il} | β_{Ie} | β_{It} | β_{Iq} | R^2 | DW |
|----|--------------------|-------------------|--------------------|--------------------|--------------------|-------------------|-------|------|
| K | 4.4483 (.4979) | -.1061 (.0367) | -.05694 (.0573) | .04955 (.0165) | .02461 (.0046) | -.1828 (.0243) | .9699 | 2.11 |
| E | -1.4421 (.8549) | .15670 (.0638) | .27820 (.0990) | -.02040 (.0289) | -.03497 (.0080) | .0737 (.0341) | .9480 | 1.25 |

Table E.8 Parameter Estimates for the Static Model for the Transportation Industry

| eq | α_1 | β_{Ik} | β_{Il} | β_{Ie} | β_{It} | β_{Iq} | R^2 | DW |
|----|-------------------|--------------------|--------------------|-------------------|--------------------|-------------------|-------|------|
| K | 4.4759 (.5998) | -.01871 (.0229) | -.13275 (.0532) | .05278 (.0201) | .02719 (.0055) | -.1728 (.0278) | .7669 | 1.87 |
| E | -.3948 (.1830) | .01370 (.0070) | .12800 (.0162) | -.1060 (.0061) | -.01121 (.0016) | .0194 (.0341) | .9775 | 1.04 |

Table E.9 Parameter Estimates for the Static Model for the Electrical Industry⁵¹

| eq | α_1 | β_{Ik} | β_{Il} | β_{Ie} | β_{It} | β_{Iq} | R^2 | DW |
|----|------------------|-------------------|--------------------|--------------------|--------------------|------------------|-------|------|
| K | .6790 (.0127) | .04261 (.0229) | -.19928 (.0474) | -.04781 (.0232) | .01112 (.0039) | ----- (-----) | .9400 | 1.25 |
| E | .0537 (.0096) | .00945 (.0204) | .29891 (.0357) | -.0207 (.0175) | -.01839 (.0029) | ----- (-----) | .9751 | 1.54 |

Table E.10 Parameter Estimates for the Static Model for the Non-Metallic Mineral Products Industry⁵²

| eq | α_1 | β_{Ik} | β_{Il} | β_{Ie} | β_{It} | β_{Iq} | R^2 | DW |
|----|-------------------|--------------------|--------------------|--------------------|------------------|-------------------|-------|------|
| K | 2.5532 (.1982) | -.03638 (.0088) | .15163 (.0237) | -.05379 (.0046) | ----- (-----) | -.0831 (.0157) | .9691 | 1.67 |
| E | -.1843 (.1982) | .01826 (.0053) | -.06557 (.0145) | .06431 (.0028) | ----- (-----) | .01099 (.0965) | .9935 | 2.34 |

⁵¹ Homotheticity imposed.

⁵² Hicks Neutral Technological Change imposed.

Table E.11 Parameter Estimates for the Static Model for the
Chemical and Chemical Products Industry⁵³

| eq | α_1 | β_{Ik} | β_{Il} | β_{Ie} | β_{It} | β_{Iq} | R^2 | DW |
|----|-------------------|--------------------|------------------|--------------------|--------------------|--------------------|-------|------|
| K | 1.3281 (.1086) | .00614 (.0050) | ----- (-----) | .02407 (.0059) | .00291 (.0005) | -.02000 (.0051) | .9691 | 1.48 |
| E | -.4409 (.0645) | -.00596 (.0030) | ----- (-----) | -.00871 (.0035) | -.00199 (.0003) | .02210 (.0308) | .9935 | 1.54 |

⁵³ Homogeneity imposed

Appendix F AES's for the Static Model

Table F.1 AES for the Rubber and Plastics Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.134 | .681 | -.020 |
| L | .681 | -2.98 | -.922 |
| E | -.020 | -.922 | 2.29 |

Table F.2 AES for the Wood Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.440 | 1.29 | 1.04 |
| L | 1.29 | -3.62 | -4.27 |
| E | 1.04 | -4.27 | 5.27 |

Table F.3 AES for the Furniture and Fixtures Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.911 | 1.25 | .259 |
| L | 1.25 | -2.02 | .298 |
| E | .259 | .298 | -1.60 |

Table F.4 AES for the Paper and Allied Products Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.191 | .583 | 1.70 |
| L | .583 | -2.32 | -3.37 |
| E | 1.70 | -3.37 | -21.31 |

Table F.5 AES for the Primary Metals Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.165 | 1.11 | 1.95 |
| L | 1.11 | -6.86 | -15.74 |
| E | 1.95 | -15.74 | 1.95 |

Table F.6 AES for the Metal Fabricating Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.543 | 1.39 | .155 |
| L | 1.39 | -3.34 | -2.12 |
| E | .155 | -2.12 | 11.25 |

Table F.7 AES for the Machinery Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.666 | 1.27 | 1.26 |
| L | 1.27 | -2.10 | -3.86 |
| E | 1.26 | -3.86 | 3.59 |

Table F.8 AES for the Transportation Equipment Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.493 | .896 | 1.14 |
| L | .896 | -2.07 | -.899 |
| E | .854 | -.211 | -7.60 |

Table F.9 AES for the Electrical Products Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | .057 | .650 | -1.24 |
| L | .650 | -22.92 | 26.02 |
| E | -3.37 | 26.02 | 61.88 |

Table F.10 AES for the Non-Metallic Mineral Products Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.255 | 1.25 | 1.38 |
| L | 1.25 | -2.95 | -13.36 |
| E | 1.38 | -13.36 | 5.56 |

Table F.11 AES for the Chemical and Chemical Products Industry

| eq | σ_{iK} | σ_{iL} | σ_{iE} |
|----|---------------|---------------|---------------|
| K | -.098 | 1.10 | 1.07 |
| L | 1.10 | -16.71 | -2.75 |
| E | 1.07 | -2.75 | -31.60 |

Appendix G Price Elasticities for the Static Model

Table G.1 Price Elasticities for the Rubber and Plastics Industry

| eq | E_{iK} | E_{iL} | E_{iE} |
|----|----------|----------|----------|
| K | -.104 | .837 | -.001 |
| L | .528 | -1.10 | -.063 |
| E | -.015 | -.146 | .159 |

Table G.2 Price Elasticities for the Wood Industry

| eq | E_{iK} | E_{iL} | E_{iE} |
|----|----------|----------|----------|
| K | -.326 | .961 | .036 |
| L | .290 | -.812 | -.148 |
| E | .772 | -.956 | .183 |

Table G.3 Price Elasticities for the Furniture and Fixtures Industry

| eq | E_{iK} | E_{iL} | E_{iE} |
|----|----------|----------|----------|
| K | -.467 | .429 | .037 |
| L | .645 | -.689 | .043 |
| E | .133 | .101 | -.234 |

Table G.4 Price Elasticities for the Paper and Allied Products Industry

| <u>eq</u> | <u>E_{iK}</u> | <u>E_{iL}</u> | <u>E_{iE}</u> |
|-----------|----------------------------|----------------------------|----------------------------|
| K | -.155 | .083 | .072 |
| L | .475 | -.331 | -.143 |
| E | 1.38 | -.480 | -.907 |

Table G.5 Price Elasticities for the Primary Metals Industry

| <u>eq</u> | <u>E_{iK}</u> | <u>E_{iL}</u> | <u>E_{iE}</u> |
|-----------|----------------------------|----------------------------|----------------------------|
| K | -.146 | .099 | .045 |
| L | .983 | -.617 | -.370 |
| E | 1.72 | -1.41 | -.045 |

Table G.6 Price Elasticities for the Metal Fabricating Industry

| <u>eq</u> | <u>E_{iK}</u> | <u>E_{iL}</u> | <u>E_{iE}</u> |
|-----------|----------------------------|----------------------------|----------------------------|
| K | -.377 | .368 | .006 |
| L | .965 | -.143 | -.085 |
| E | .107 | -.561 | .455 |

Table G.7 Price Elasticities for the Machinery Industry

| eq | E_{iK} | E_{iL} | E_{iE} |
|----|----------|----------|----------|
| K | -.437 | .351 | .083 |
| L | .834 | -.581 | -.255 |
| E | .827 | -1.06 | .237 |

Table G.8 Price Elasticities for the Transportation Equipment Industry

| eq | E_{iK} | E_{iL} | E_{iE} |
|----|----------|----------|----------|
| K | -.365 | .207 | .030 |
| L | .664 | -.480 | -.023 |
| E | .633 | -.048 | -.202 |

Table G.9 Price Elasticities for the Electrical Products Industry

| eq | E_{iK} | E_{iL} | E_{iE} |
|----|----------|----------|----------|
| K | .038 | .174 | -.070 |
| L | .438 | -6.14 | 31.48 |
| E | -2.27 | 6.97 | 3.53 |

**Table G.10 Price Elasticities for the
Non-metallic Mineral Products Industry**

| <u>eq</u> | <u>E_{1K}</u> | <u>E_{1L}</u> | <u>E_{1E}</u> |
|-----------|----------------------------|----------------------------|----------------------------|
| K | -.213 | .136 | .075 |
| L | 1.04 | -.323 | -.727 |
| E | 1.15 | -1.46 | .302 |

**Table G.11 Price Elasticities for the Chemical and Chemical
Products Industry**

| <u>eq</u> | <u>E_{1K}</u> | <u>E_{1L}</u> | <u>E_{1E}</u> |
|-----------|----------------------------|----------------------------|----------------------------|
| K | -.089 | .061 | .028 |
| L | 1.00 | -.936 | -.072 |
| E | .981 | -.154 | -.835 |

Appendix H AES's for the Dynamic Model

Table H.1 AES for the Rubber and Plastics Industry

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -.145 | .610 | .266 |
| L | .610 | -1.19 | -4.63 |
| E | .266 | -4.63 | 8.55 |

Table H.2 AES for the Wood Industry:

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -.211 | .298 | 2.85 |
| L | .298 | .253 | -8.88 |
| E | 2.85 | -8.88 | -3.52 |

Table H.3 AES for the Furniture and Fixtures Industry

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -2.55 | 1.32 | 6.87 |
| L | 1.32 | -1.34 | -1.78 |
| E | 6.87 | -1.78 | -23.25 |

Table H.4 AES for the Paper and Allied Industries

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -.164 | .455 | 1.65 |
| L | .455 | -.985 | -5.47 |
| E | 1.65 | -5.47 | -13.45 |

Table H.5 AES for the Primary Metals Industry

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -.127 | -19.37 | 2.19 |
| L | -19.37 | -2.31 | 1.92 |
| E | 2.19 | 1.92 | 2.19 |

Table H.6 AES for the Metal Fabricating Industry

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -1.17 | 19.94 | -123.25 |
| L | 19.94 | -394.22 | 2498.80 |
| E | -123.25 | 2490.80 | -15899.64 |

Table H.7 AES for the Machinery Industry

| <u>equation</u> | <u>σ_{iK}</u> | <u>σ_{iL}</u> | <u>σ_{iE}</u> |
|-----------------|---------------------------------|---------------------------------|---------------------------------|
| K | -.959 | -2.19 | 21.17 |
| L | -2.19 | 45.08 | -188.99 |
| E | 21.17 | -188.99 | 657.76 |

Table H.8 AES for the Transportation Equipment Industry

| <u>equation</u> | <u>σ_{iK}</u> | <u>σ_{iL}</u> | <u>σ_{iE}</u> |
|-----------------|---------------------------------|---------------------------------|---------------------------------|
| K | -1.98 | 4.46 | 18.03 |
| L | 4.46 | -9.28 | -47.77 |
| E | 18.03 | -47.77 | -96.11 |

Table H.9 AES for the Electrical Products Industry

| <u>equation</u> | <u>σ_{iK}</u> | <u>σ_{iL}</u> | <u>σ_{iE}</u> |
|-----------------|---------------------------------|---------------------------------|---------------------------------|
| K | -.120 | .082 | 1.16 |
| L | .082 | .033 | -1.26 |
| E | 1.16 | -1.26 | -8.75 |

Table H.10 AES for the Non-metallic Mineral Products Industry

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -.196 | 1.28 | .464 |
| L | 1.28 | -8.59 | -2.56 |
| E | .464 | -2.56 | -2.09 |

Table H.11 AES for the Chemical and Chemical Products Industry

| equation | σ_{iK} | σ_{iL} | σ_{iE} |
|----------|---------------|---------------|---------------|
| K | -.089 | 1.03 | .902 |
| L | 1.03 | -17.52 | 1.30 |
| E | .902 | 1.30 | -34.08 |

Appendix I Price Elasticities for the Dynamic Model

Table I.1 Price Elasticities For the Rubber and Plastics Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -.113 | .096 | .016 |
| L | .475 | -.189 | -.285 |
| E | .207 | -.735 | .527 |

Table I.2 Price Elasticities For the Wood Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -.156 | .067 | .089 |
| L | .221 | .057 | -.278 |
| E | 2.11 | -2.00 | -.110 |

Table I.3 Price Elasticities For the Furniture and Fixtures Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -1.34 | .455 | .885 |
| L | .694 | -.462 | -.229 |
| E | 3.61 | -.614 | -2.99 |

Table I.4 Price Elasticities For the Paper and Allied Products Industry

| $i=$ | E_{iK} | E_{iL} | E_{iE} |
|------|----------|----------|----------|
| K | -.133 | .064 | .069 |
| L | .371 | -.140 | -.230 |
| E | 1.34 | -.777 | -.567 |

Table I.5 Price Elasticities For the Primary Minerals Industry

| $i=$ | E_{iK} | E_{iL} | E_{iE} |
|------|----------|----------|----------|
| K | -.112 | -1.75 | .051 |
| L | -17.15 | -.209 | .044 |
| E | 1.94 | .174 | .051 |

Table I.6 Price Elasticities For the Metal Fabricating Industry

| $i=$ | E_{iK} | E_{iL} | E_{iE} |
|------|----------|----------|----------|
| K | -.817 | 5.28 | -4.47 |
| L | 13.92 | -104.57 | 90.64 |
| E | -86.08 | 660.50 | -576.75 |

Table I.7 Price Elasticities For the Machinery Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -.634 | -.580 | .767 |
| L | -1.44 | 11.95 | -6.85 |
| E | 14.01 | -50.10 | 23.86 |

Table I.8 Price Elasticities For the Transportation Equipment Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -1.47 | 1.03 | .444 |
| L | 3.31 | -2.14 | -1.17 |
| E | 13.41 | -11.04 | -2.36 |

Table I.9 Price Elasticities for the Electrical Products Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -.081 | .021 | .059 |
| L | .055 | .008 | -.065 |
| E | .789 | -.337 | -.451 |

Table I.10 Price Elasticities for the Non-metallic Mineral Products Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -.164 | .141 | .023 |
| L | 1.07 | -.947 | -.131 |
| E | .388 | -.282 | -.107 |

Table I.11 Price Elasticities for the Chemical and Chemical Products Industry

| $i =$ | E_{iK} | E_{iL} | E_{iE} |
|-------|----------|----------|----------|
| K | -.081 | .057 | .023 |
| L | .945 | -.981 | .034 |
| E | .827 | .072 | -.901 |

Appendix J Empirical Results for the Dynamic Model

Table J.1 Parameter Estimates for the Dynamic Model for the Rubber and Plastics Industry (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|--------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------------------|-------------------|--------------------|-------------------|-------------------|--------------------|-------------------|-------------------|
| 1 | -2.9878 (.5785) | .1824 (.2584) | -.6279 (.2823) | -.1017 (.0288) | -.0168 (.0110) | .05600 (.0647) | .00462 (.0040) | -.0251 (.0288) | -.14161 (.0387) | .08544 (.0295) | -.01238 (.0185) | .07210 (.0144) | .55423 (.0655) | -.36529 (.0492) | .11441 (.0175) | .17097 (.0130) |
| | DW 2.3175 R ² .9098 | | | | | | | | | | | | | | | |
| 2 | 5.7441 (.6869) | 1.1946 (.3147) | 2.0174 (.3425) | .03731 (.0356) | .05684 (.0147) | .11343 (.0798) | -.0673 (.0191) | -.0144 (.0048) | - | - | - | - | - | - | - | - |
| | DW 2.0284 R ² .9514 | | | | | | | | | | | | | | | |

Table J.2 Parameter Estimates for the Dynamic Model for the Wood Industry (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|--------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|--------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 1 | .99138 (.3643) | .20522 (.1135) | -.1406 (.0808) | -.0807 (.0136) | -.0546 (.0140) | .05182 (.0463) | -.02476 (.0053) | -.0035 (.0012) | -.0276 (.0159) | .11761 (.0329) | -.1296 (.0456) | .28608 (.0945) | .40548 (.1251) | -.7394 (.2589) | -.1178 (.0531) | .19923 (.1101) |
| | DW 2.4706 R ² .9482 | | | | | | | | | | | | | | | |
| 2 | .36096 (.4874) | 1.0545 (.1539) | .66020 (.1077) | .11175 (.0188) | .02239 (.0184) | .01586 (.0646) | -.0568 (.0074) | -.0009 (.0009) | - | - | - | - | - | - | - | - |
| | DW 2.5691 R ² .9675 | | | | | | | | | | | | | | | |

Table J.3 Parameter Estimates for the Dynamic Model for the Furniture and Fixtures Industry (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|--------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-----------|
| 1 | 3.7684 (1.186) | -.2498 (.1314) | -.4471 (.2520) | -.2244 (.0388) | -.1273 (.0418) | 1.1977 (.2249) | -.3046 (.0503) | .28658 (.0847) | -.1125 (.0443) | -.1809 (.1247) | .24470 (.0666) | -.2684 (.2383) | -.6122 (.3917) | .42916 (.1333) | .22035 (.2635) | |
| | DW 2.1631 R ² .9450 | | | | | | | | | | | | | | | |
| 2 | -2.4195 (.9375) | .25526 (.0545) | .07396 (.0739) | .24233 (.0335) | -.0109 (.0398) | -.6727 (.2158) | .0272 (.0487) | - | - | - | - | - | - | - | - | - |
| | DW 2.4480 R ² .8869 | | | | | | | | | | | | | | | |

Table J.4 Parameter Estimates for the Dynamic Model for the Paper and Allied Products Industry⁵⁴ (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} |
|----|-----------------------------|--------------------|-------------------|--------------------|--------------------|--------------------|-------------------|
| 1 | .57963 (.4626) | .44512 (.0063) | .33545 (.0078) | -.01237 (.0154) | .00046 (.0068) | -.01092 (.1836) | .02501 (.2229) |
| DW | 1.8361 R ² .3944 | | | | | | |
| 2 | .69222 (.0065) | -.39892 (.2868) | .20486 (.3480) | .03951 (.0065) | -.00488 (.0133) | -.01470 (.0239) | .69222 (.0115) |
| DW | 1.9195 R ² .7177 | | | | | | |

Table J.5 Parameter Estimates for the Dynamic Model for the Primary Metals Industry⁵⁵ (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} |
|----|-----------------------------|-------------------|-------------------|--------------------|--------------------|--------------------|
| 1 | .26258 (.4626) | .69488 (.0063) | .27915 (.0078) | .01319 (.0154) | .02727 (.0068) | -.03958 (.1836) |
| DW | 1.8575 R ² .4423 | | | | | |
| 2 | .73768 (.1330) | .13835 (.1572) | .84000 (.1557) | -.00955 (.0083) | -.03493 (.0072) | .05517 (.0551) |
| DW | 1.7867 R ² .4529 | | | | | |

Table J.6 Parameter Estimates for the Dynamic Model for the Metal Fabricating Industry (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|-----------------------------|-------------------|-------------------|--------------------|--------------------|--------------------|--------------------|------------------|-------------------|-------------------|--------------------|-------------------|-------------------|--------------------|--------------------|--------------------|
| 1 | -1.7509 (.4656) | -.2770 (.1108) | -.6630 (.1139) | -.01921 (.0098) | -.00966 (.0066) | -.06142 (.0090) | -.01921 (.0260) | ----- (-----) | .01673 (.0104) | -.0005 (.0087) | -.13200 (.0302) | .08328 (.0255) | .22389 (.0601) | -.05672 (.0509) | -.03327 (.0237) | -.07564 (.0200) |
| DW | 2.8151 R ² .9501 | | | | | | | | | | | | | | | |
| 2 | 4.3075 (1.046) | 1.2988 (.2481) | 1.4385 (.2580) | -.07146 (.0233) | .03325 (.0152) | -.04197 (.0212) | .14365 (.0579) | ----- (-----) | - | - | - | - | - | - | - | - |
| DW | 2.7018 R ² .8082 | | | | | | | | | | | | | | | |

⁵⁴ Autoregressive model

⁵⁵ Autoregressive model

Table J.7 Parameter Estimates for the Dynamic Model for the Machinery Industry (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|--------------------------------|------------------|-------------------|--------------------|--------------------|--------------------|-------------------|--------------------|--------------------|-------------------|--------------------|-------------------|-------------------|-------------------|--------------------|--------------------|
| 1 | -1.0542 (.4989) | .2148 (.0626) | -.2809 (.1363) | -.11048 (.0091) | .01371 (.0110) | -.04728 (.0276) | .00888 (.0071) | -.01504 (.0018) | -.17997 (.0318) | .10240 (.0141) | -.19906 (.0696) | .01070 (.0291) | .92197 (.1219) | .28177 (.0520) | -.00845 (.0356) | -.15994 (.0149) |
| | DW 2.1574 R ² .9869 | | | | | | | | | | | | | | | |
| 2 | 5.8554 (1.171) | .3618 (.1428) | 1.4552 (.3149) | -.16237 (.0214) | -.01163 (.0245) | .17600 (.0624) | .02417 (.0163) | -.16237 (.0043) | - | - | - | - | - | - | - | - |
| | DW 2.4515 R ² .9508 | | | | | | | | | | | | | | | |

Table J.8 Parameter Estimates for the Dynamic Model for the Transportation Equipment Industry (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|--------------------------------|-------------------|-------------------|--------------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|--------------------|-------------------|-------------------|--------------------|--------------------|-------------------|
| 1 | .6274 (.1190) | .2532 (.0709) | .07391 (.0490) | -.04958 (.0043) | .01546 (.0052) | .03262 (.0084) | .00391 (.0164) | ----- (.-----) | -.59165 (1.586) | 1.7647 (4.531) | -.15017 (.2297) | .32628 (.6547) | 1.4595 (3.552) | -3.9781 (10.14) | -.50905 (1.307) | 1.3866 (3.733) |
| | DW 2.6161 R ² .9269 | | | | | | | | | | | | | | | |
| 2 | -.06171 (.4191) | 1.2285 (.2775) | .46575 (.1815) | .078140 (.0174) | .010708 (.0304) | .02666 (.0586) | -.12791 (.0155) | ----- (.-----) | - | - | - | - | - | - | - | - |
| | DW 2.8599 R ² .9364 | | | | | | | | | | | | | | | |

Table J.9 Parameter Estimates for the Dynamic Model for the Electrical Products Industry (standard errors in parenthesis).

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|--------------------------------|-------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|-------------------|--------------------|-------------------|-------------------|--------------------|--------------------|--------------------|
| 1 | -.59171 (.1190) | .0561 (.0709) | -.09603 (.0490) | -.04860 (.0043) | -.02762 (.0052) | -.02762 (.0084) | -.09603 (.0164) | -.00224 (.0024) | -.05256 (1.586) | .01539 (4.531) | -.11014 (.2297) | .19473 (.6547) | .33551 (3.552) | -.30939 (10.14) | -.00836 (1.307) | -.02779 (3.733) |
| | DW 2.9038 R ² .9655 | | | | | | | | | | | | | | | |
| 2 | 1.6336 (.4191) | 1.4384 (.2775) | 1.4208 (.1815) | .07926 (.0174) | -.00131 (.0304) | .10821 (.0586) | -.03871 (.0155) | -.00854 (.0045) | - | - | - | - | - | - | - | - |
| | DW 2.5710 R ² .8719 | | | | | | | | | | | | | | | |

Table J.10 Parameter Estimates for the Dynamic Model for the Non-metallic Minerals Industry (standard errors in parenthesis).⁵⁶

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|-------------------|----------------------|-------------------|--------------------|--------------------|--------------------|--------------------|-------------------|-------------------|--------------------|---------------------|--------------------|------------------|------------------|-------------------|--------------------|
| 1 | .18083 (.4517) | 1.5139 (.3672) | .51608 (.2349) | .02762 (.0136) | .00169 (.0113) | -.08501 (.0363) | .02762 (.0065) | .00169 (.0014) | .06814 (.0065) | -.05285 (.0090) | -.036843 (.0129) | -.07308 (.0177) | ----- (-----) | ----- (-----) | .04033 (.0150) | -.08897 (.0210) |
| | DW 2.1830 | R ² .8941 | | | | | | | | | | | | | | |
| 2 | 2.2428 (.6692) | -.32624 (.5338) | .76077 (.3410) | -.01948 (.0204) | -.05119 (.0166) | .01183 (.0513) | -.08649 (.0123) | .00485 (.0021) | - | - | - | - | - | - | - | - |
| | DW 2.3273 | R ² .8863 | | | | | | | | | | | | | | |

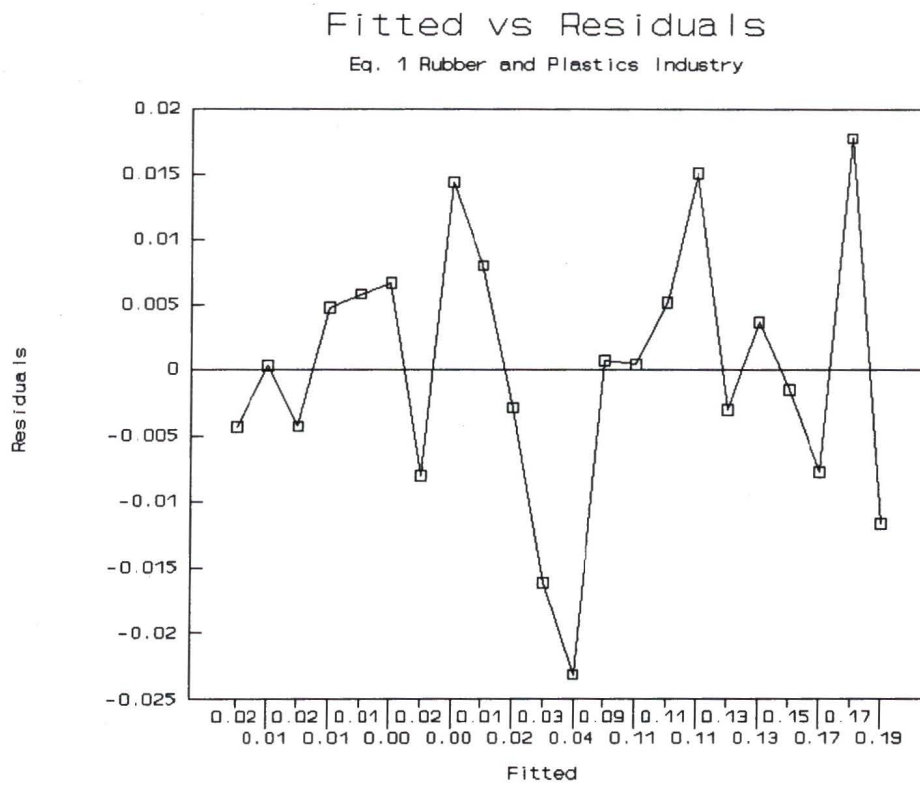
Table J.11 Parameter Estimates for the Dynamic Model for the Chemical and Chemical Products Industry (standard errors in parenthesis).⁵⁷

| eq | α_1 | γ_{11} | γ_{12} | β_{11} | β_{12} | β_{13} | β_{Q1} | β_{T1} | δ_{11} | δ_{21} | δ_{12} | δ_{22} | δ_{13} | δ_{23} | β_1 | β_2 |
|----|--------------------|----------------------|--------------------|--------------------|---------------------|-------------------|-------------------|--------------------|--------------------|-------------------|--------------------|-------------------|------------------|------------------|-------------------|--------------------|
| 1 | -.15944 (.1285) | 1.9429 (.3799) | .41140 (.1750) | -.01909 (.0044) | -.00559 (.0025) | .00841 (.0125) | .00246 (.0050) | -.00177 (.0004) | -.00539 (.0027) | .02444 (.0086) | -.00539 (.0035) | .01647 (.0109) | ----- (-----) | ----- (-----) | .01723 (.0021) | -.01430 (.0069) |
| | DW 2.1932 | R ² .7478 | | | | | | | | | | | | | | |
| 2 | .7344 (.7344) | -2.2277 (.7106) | -.01471 (.3307) | .04291 (.0085) | .0053891 (.0053) | .02970 (.0251) | .01599 (.0099) | .00299 (.0008) | - | - | - | - | - | - | - | - |
| | DW 2.0906 | R ² .7009 | | | | | | | | | | | | | | |

⁵⁶ Homogeneity imposed

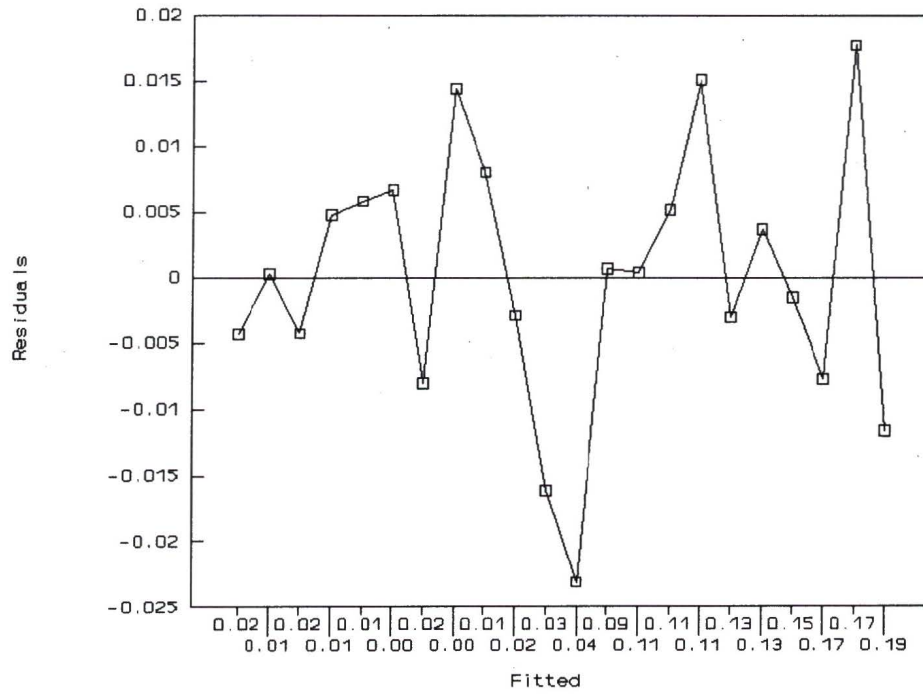
⁵⁷ Static Model

Appendix R1 Fitted vs Residuals Static Model



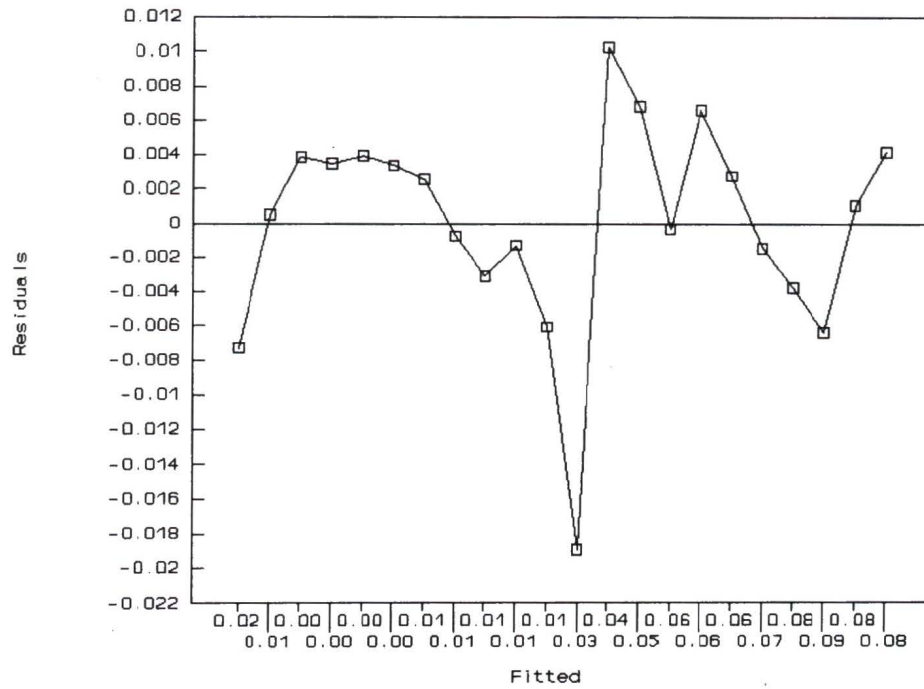
Fitted vs Residuals

Eq. 2 Rubber and Plastics Industry



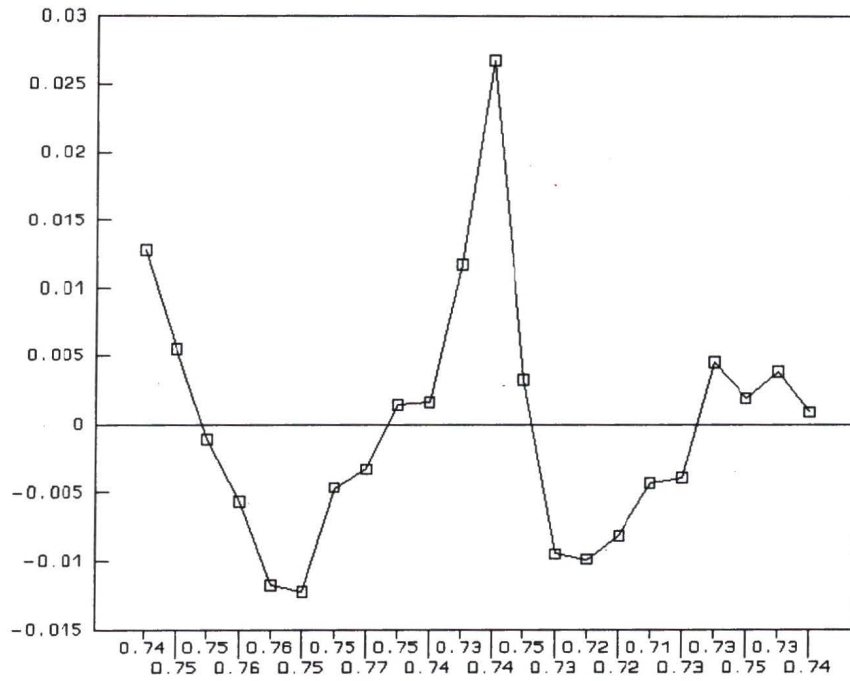
Fitted vrs. Residuals

Eq. 1 Wood Industry



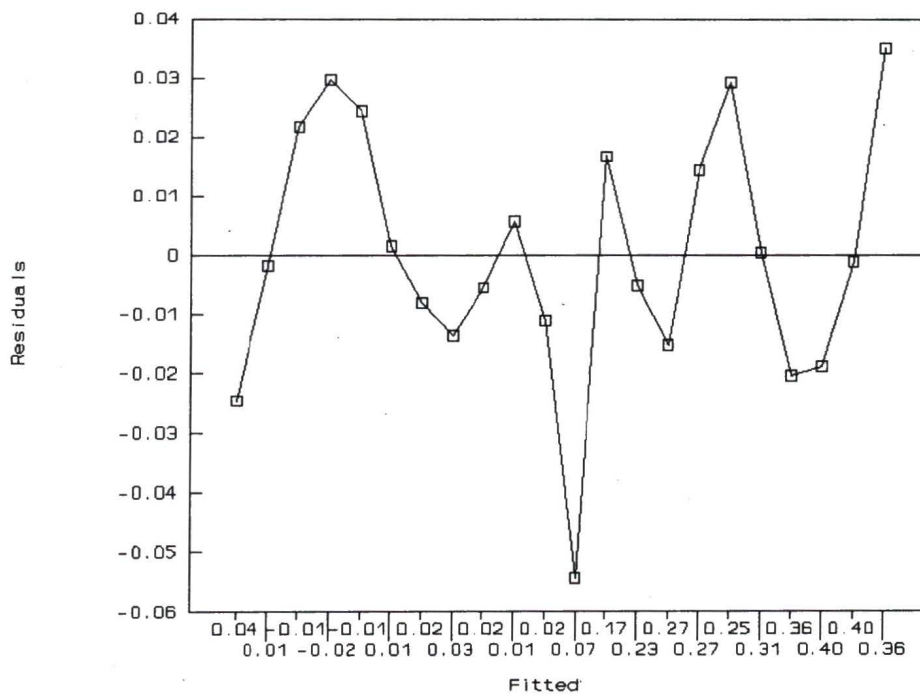
Fitted vs Residuals

Eq. 2 Wood Industry



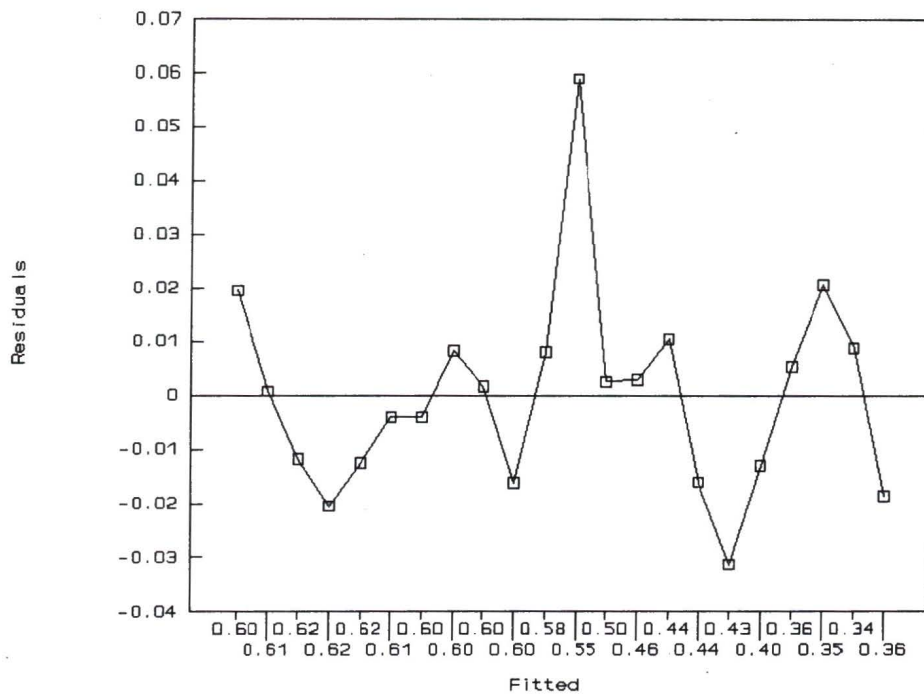
Fitted vs Residuals

Eq. 1 Furnitures and Fixtures Industry



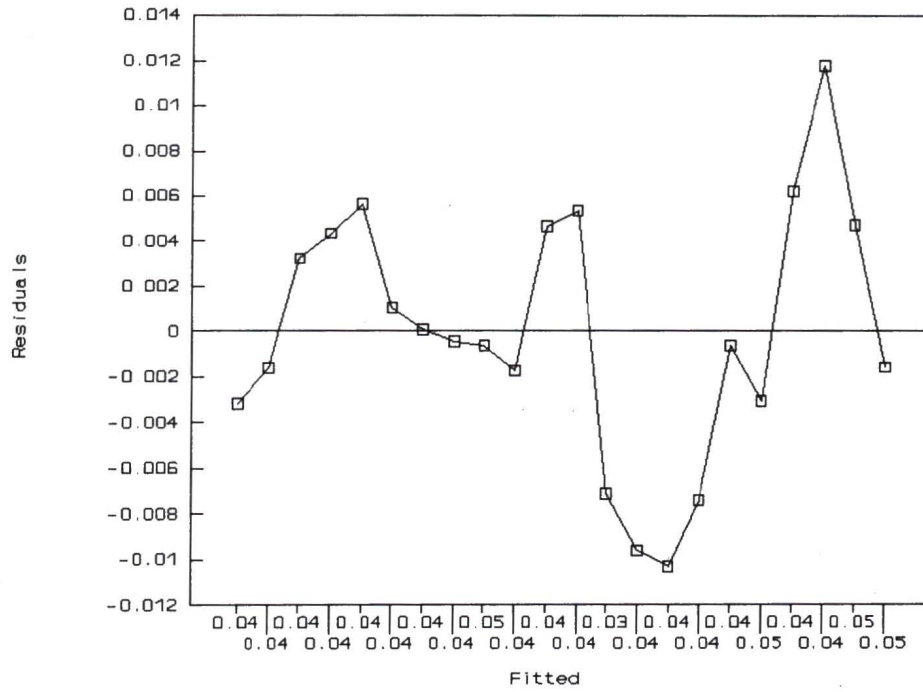
Fitted vs Residuals

Eq. 2 Furnitures and Fixtures Industry



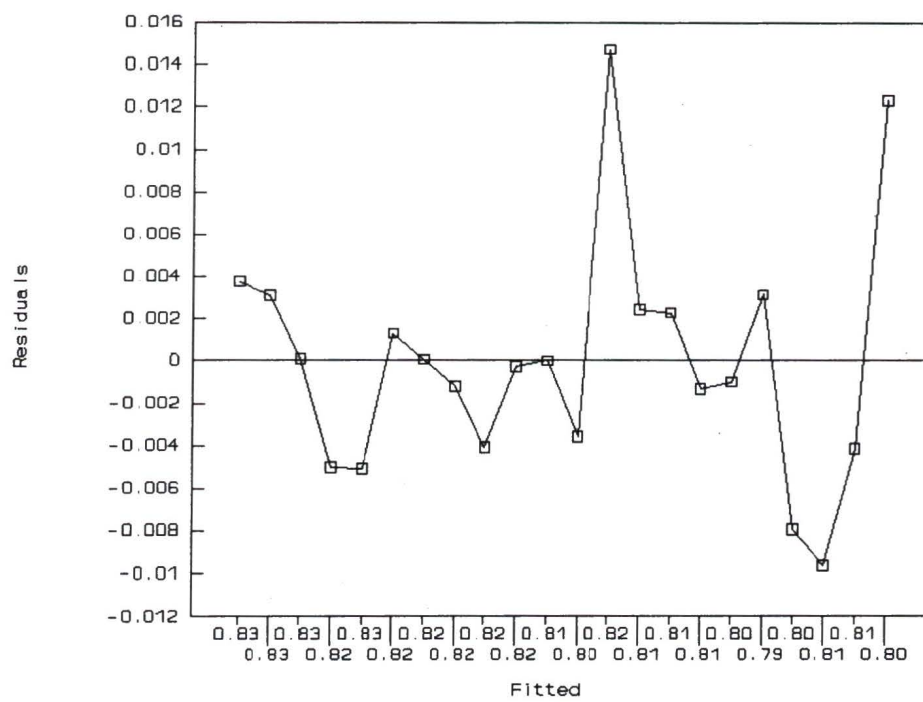
Fitted vs Residuals

Eq. 1 Paper and Allied Industry



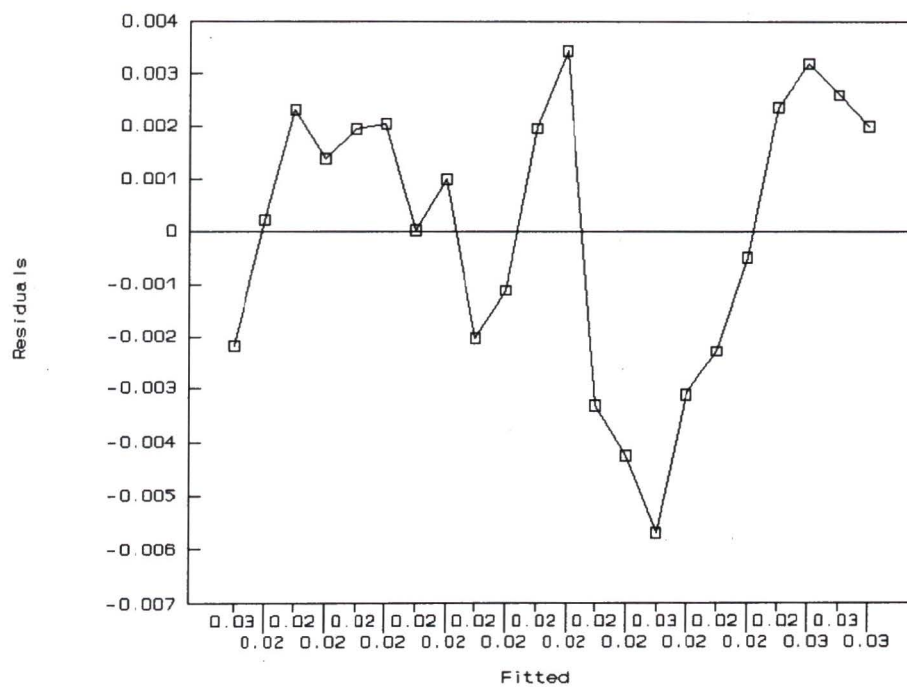
Fitted vs Residuals

Eq. 2 Paper and Allied Industry



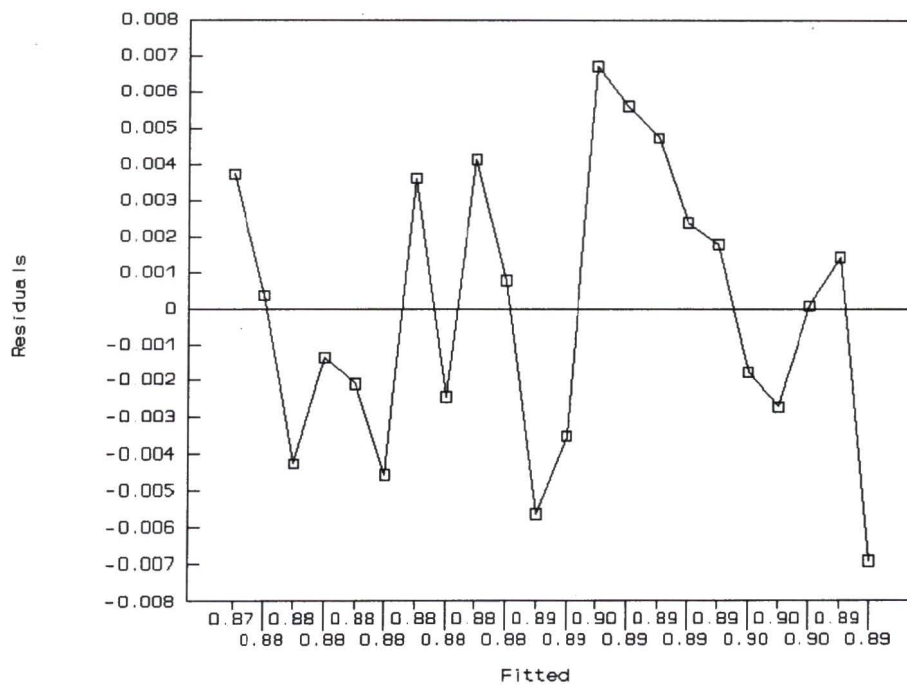
Fitted vs Residuals

Eq. 1 Primary Metals Industry



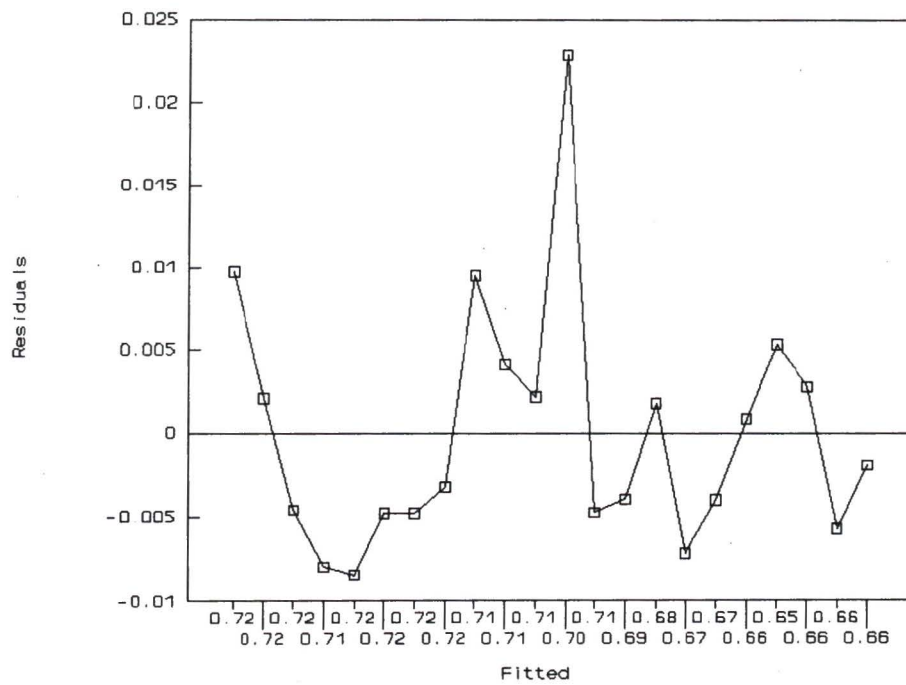
Fitted vs Residuals

Eq. 2 Primary Metals Industry



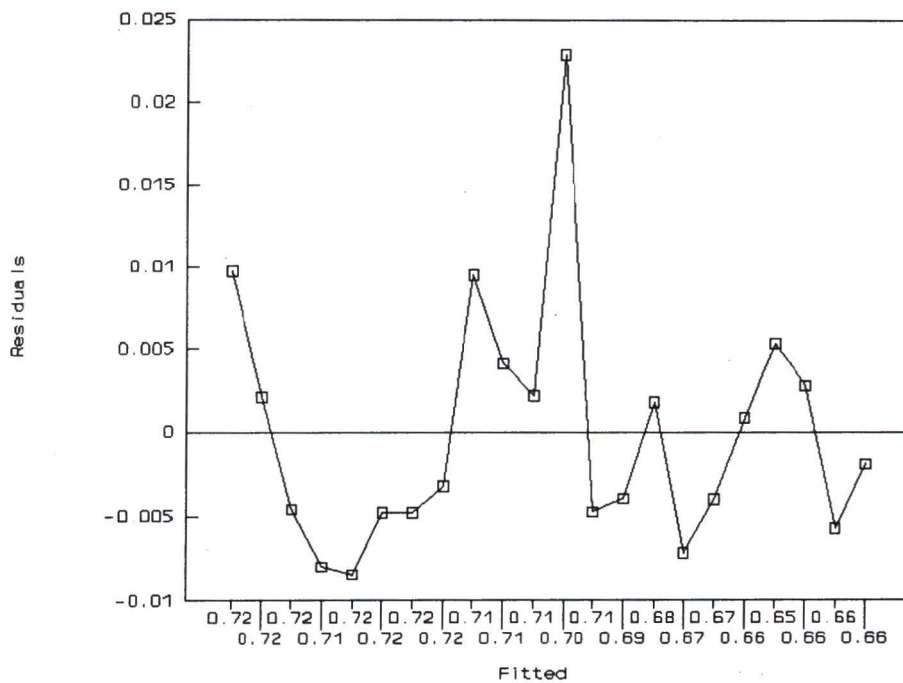
Fitted vs Residuals

Eq. 2 Metal Fabricating Industry



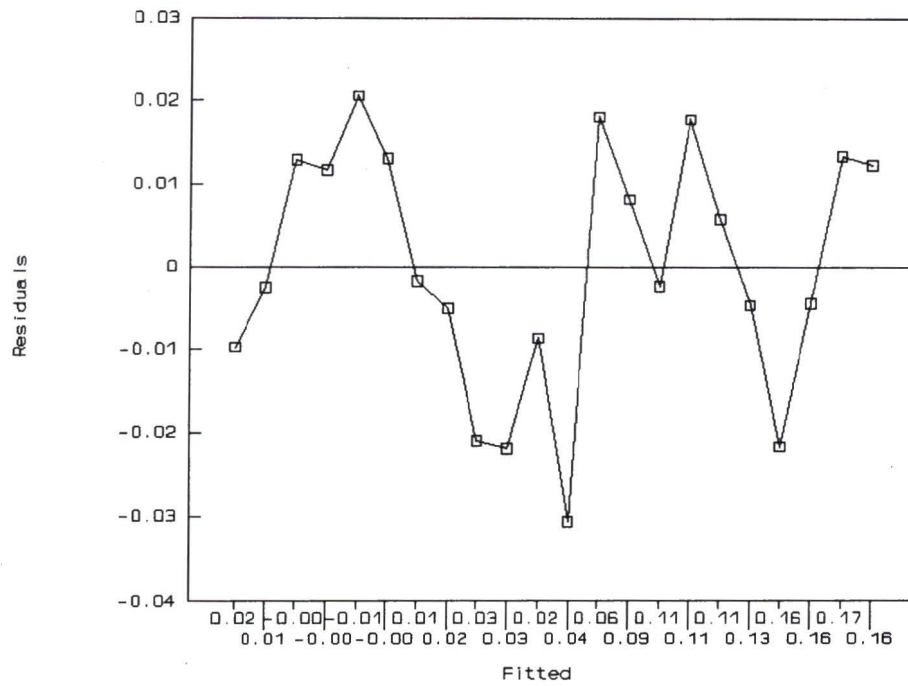
Fitted vs Residuals

Eq. 2 Metal Fabricating Industry



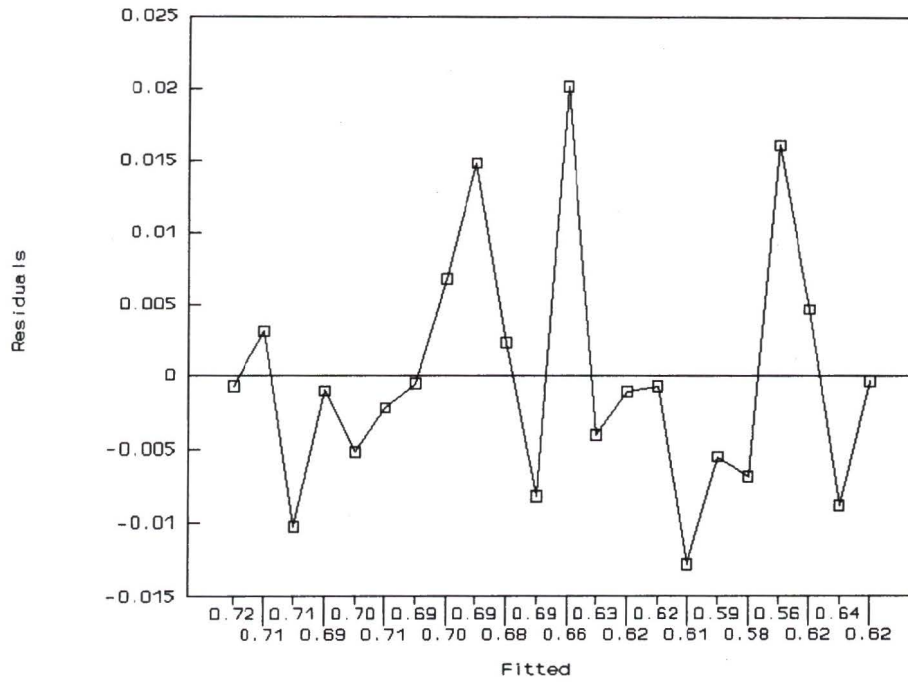
Fitted vs Residuals

Eq. 1 Machinery Industry



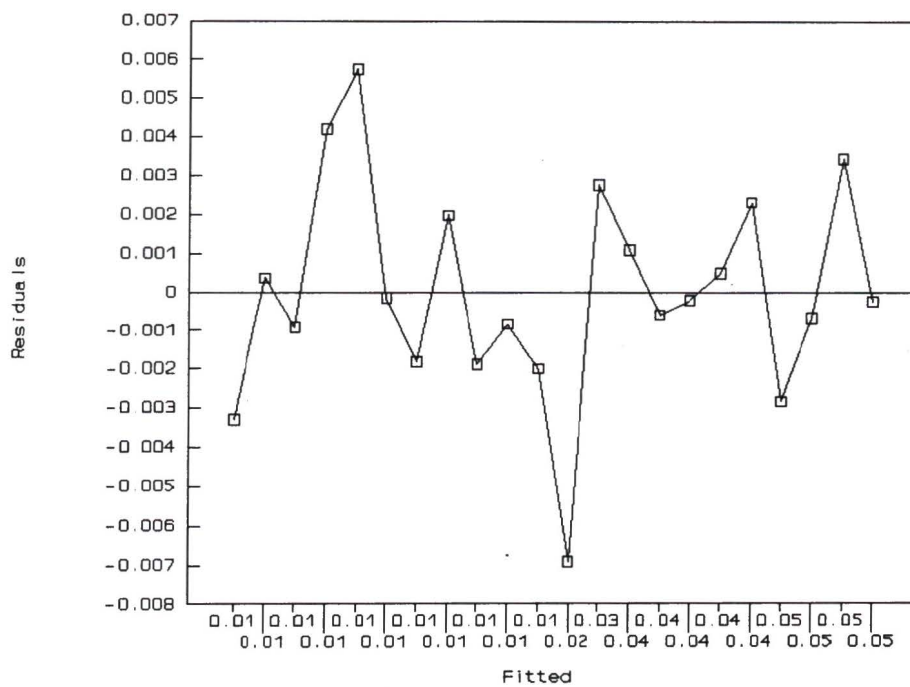
Fitted vs Residuals

Eq. 2 Machinery Industry



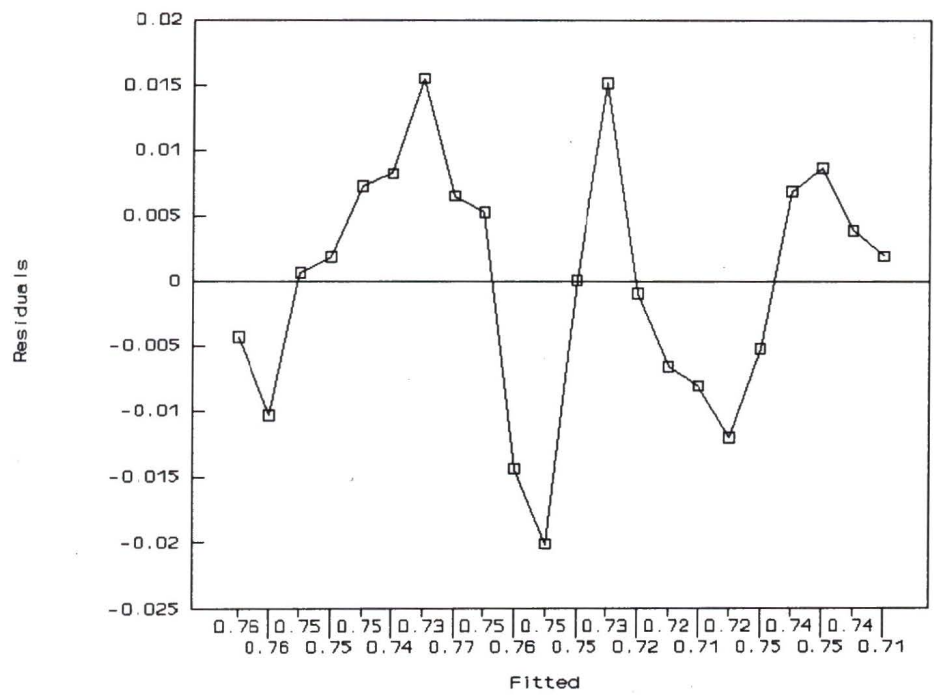
Fitted vs Residuals

Eq. 1 Transportation Equipment Industry



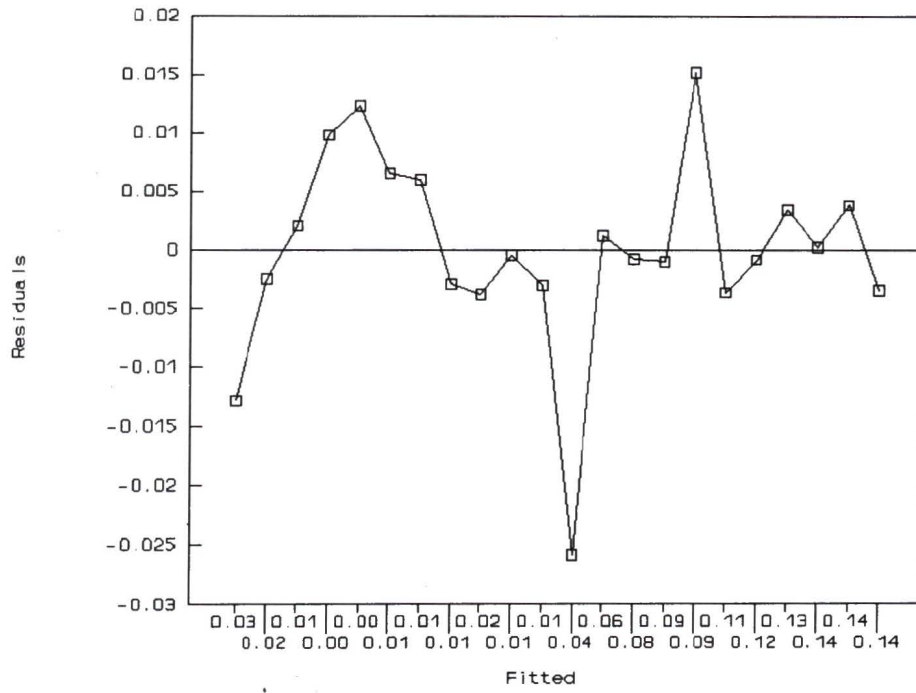
Fitted vs Residuals

Eq. 2 Transportation Equipment Industry



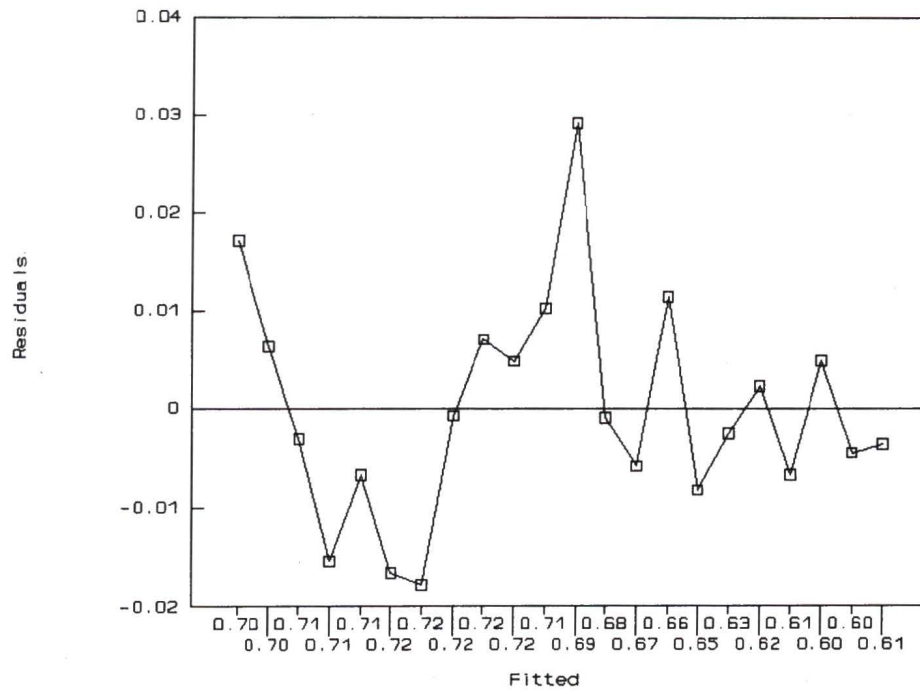
Fitted vs Residuals

Eq. 1 Electrical Products Industry



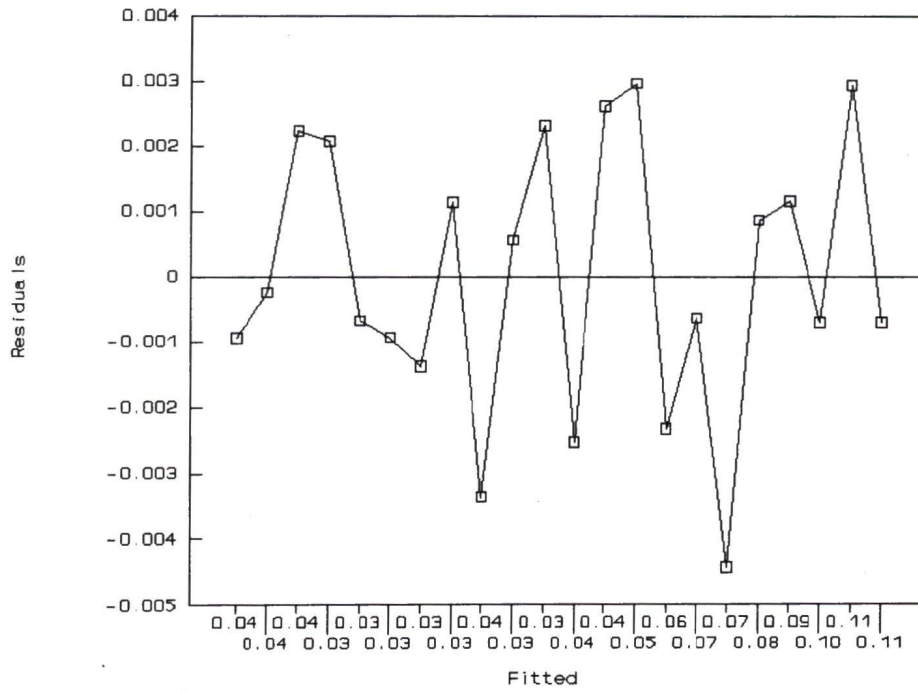
Fitted vs Residuals

Eq. 2 Electrical Products Industry



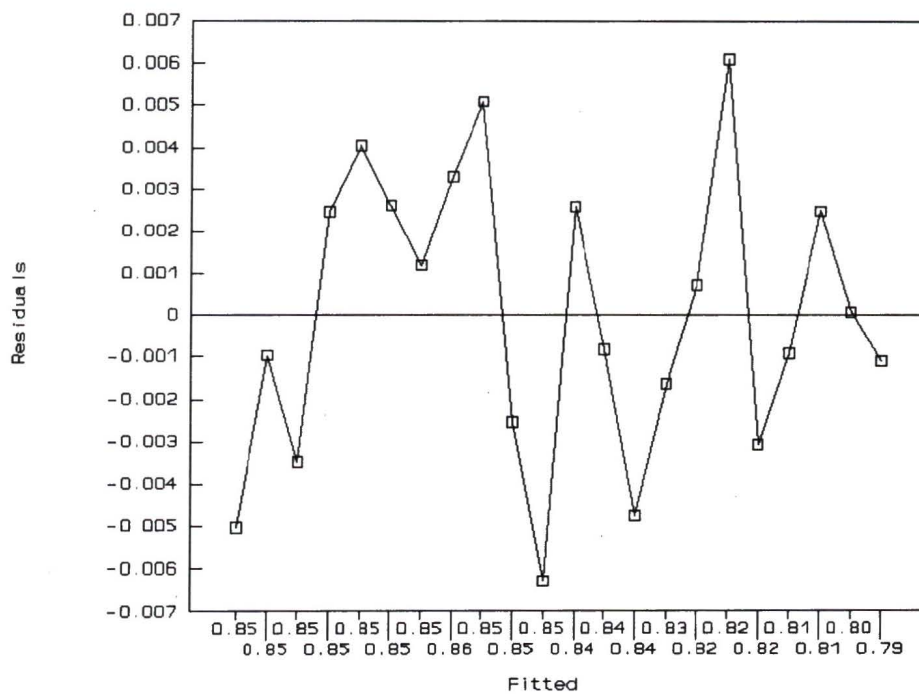
Fitted vs Residuals

Eq. 1 Non-metallic Mineral Products



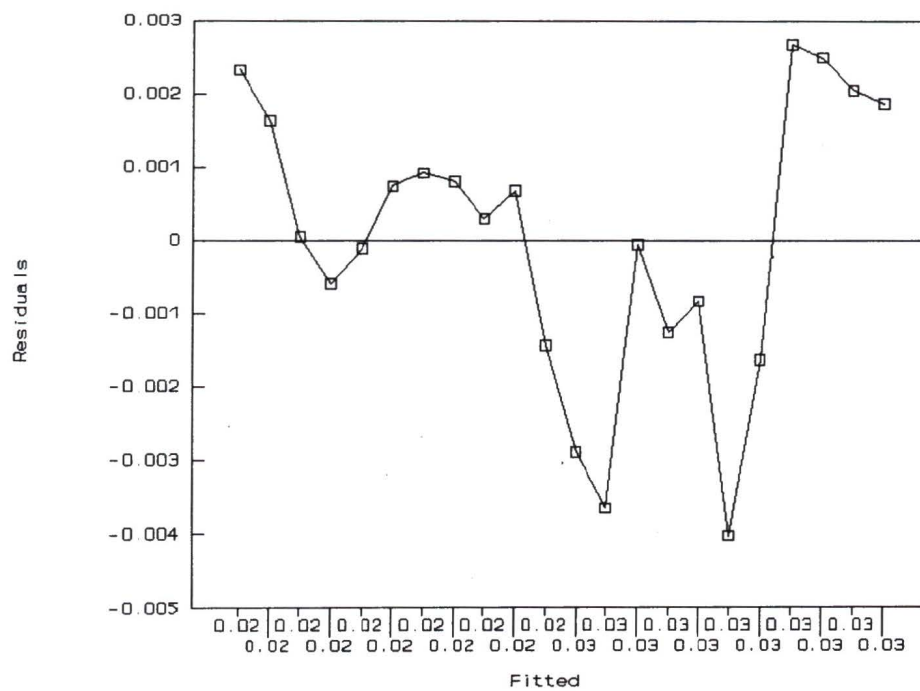
Fitted vs Residuals

Eq. 2 Non-metallic Mineral Products



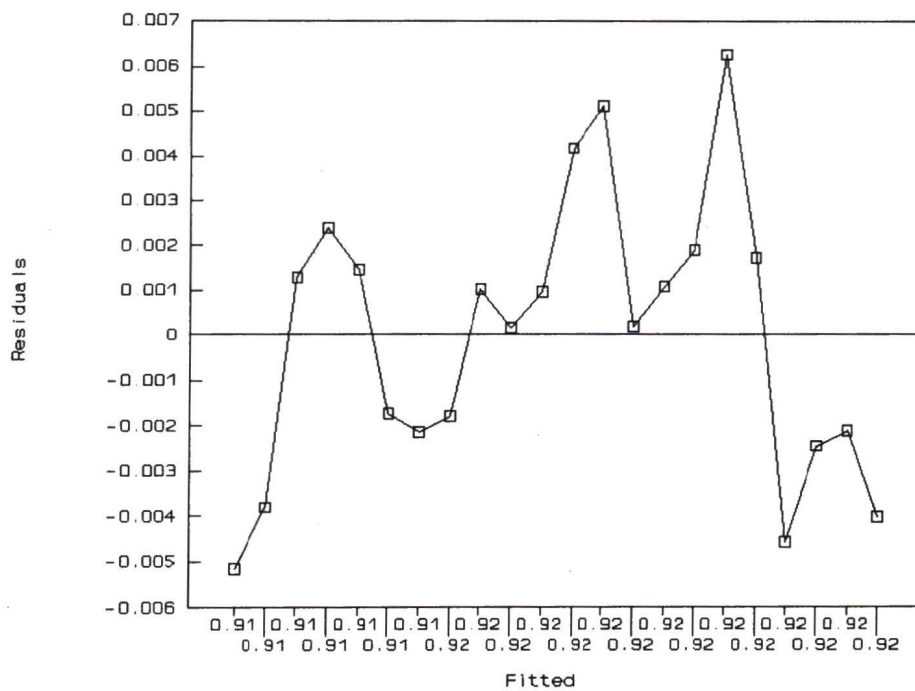
Fitted vs Residuals

Eq. 1 Chemical and Chemical Products



Fitted vs Residuals

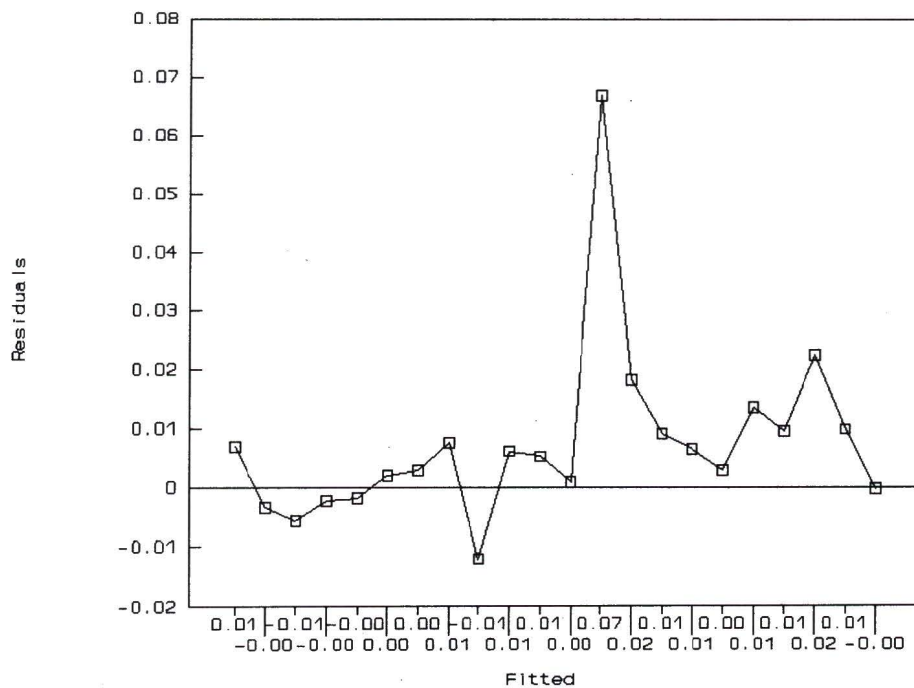
Eq. 2 Chemical and Chemical Products



Appendix R2 Fitted vs Residuals Dynamic Model

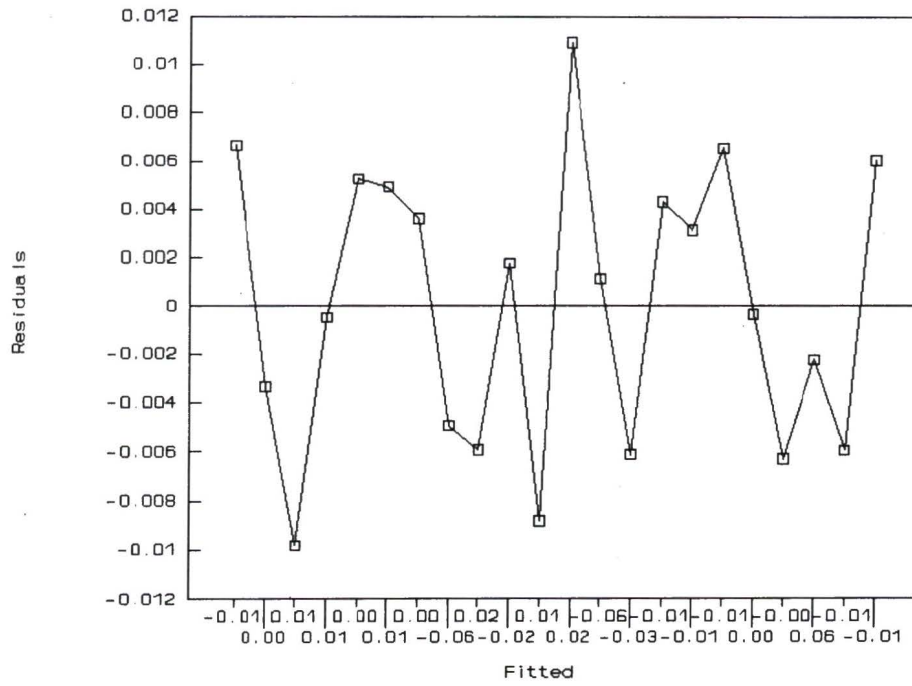
Fitted vs Residuals

Eq. 1 Rubber and Plastics Industry



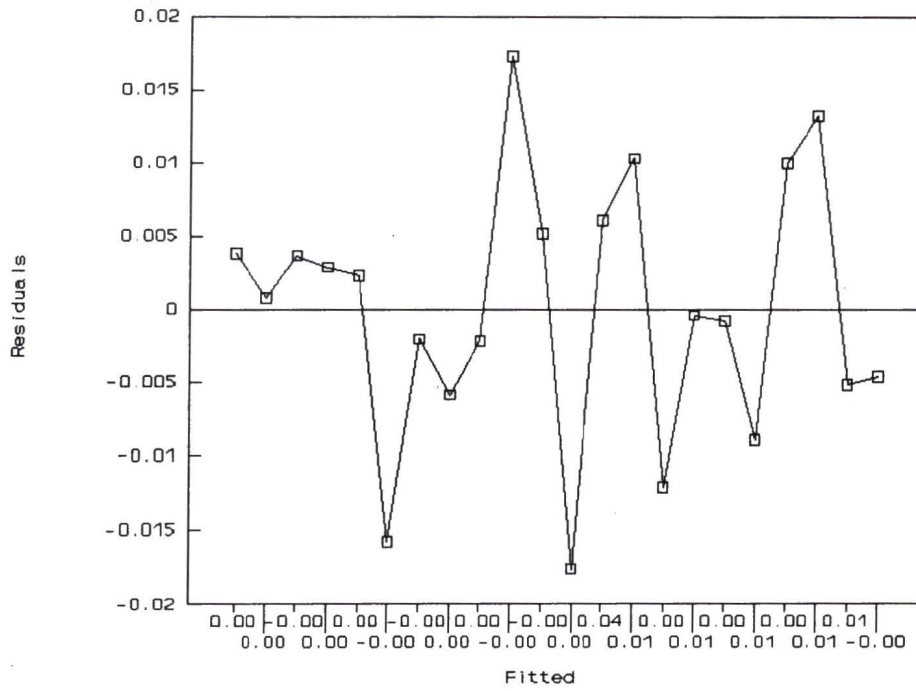
Fitted vs. Residuals

EQ. 2 Rubber and Plastics Industry



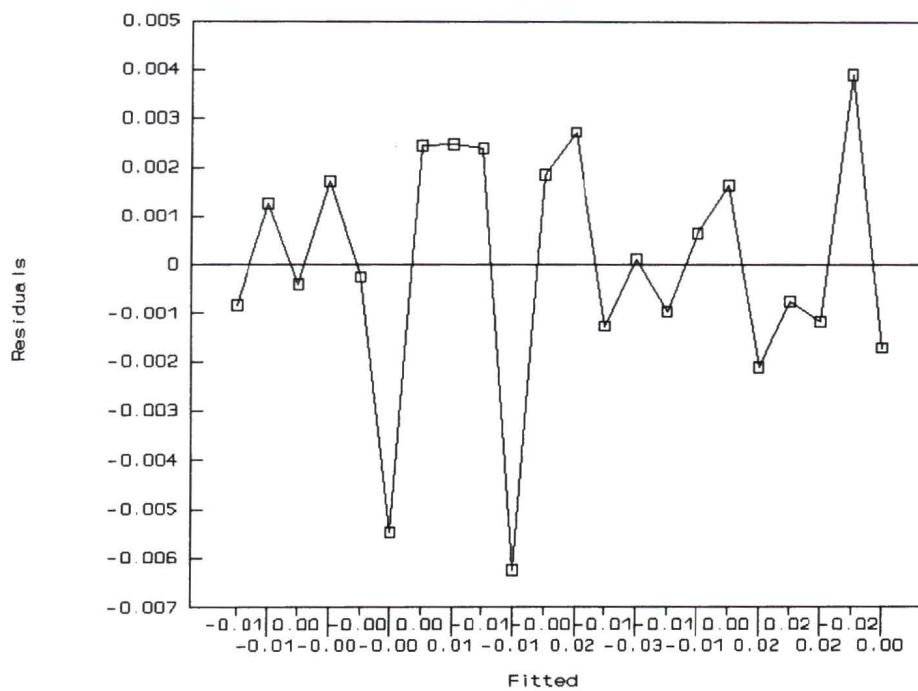
Fitted vs. Residuals

Eq. 1 Wood Industry



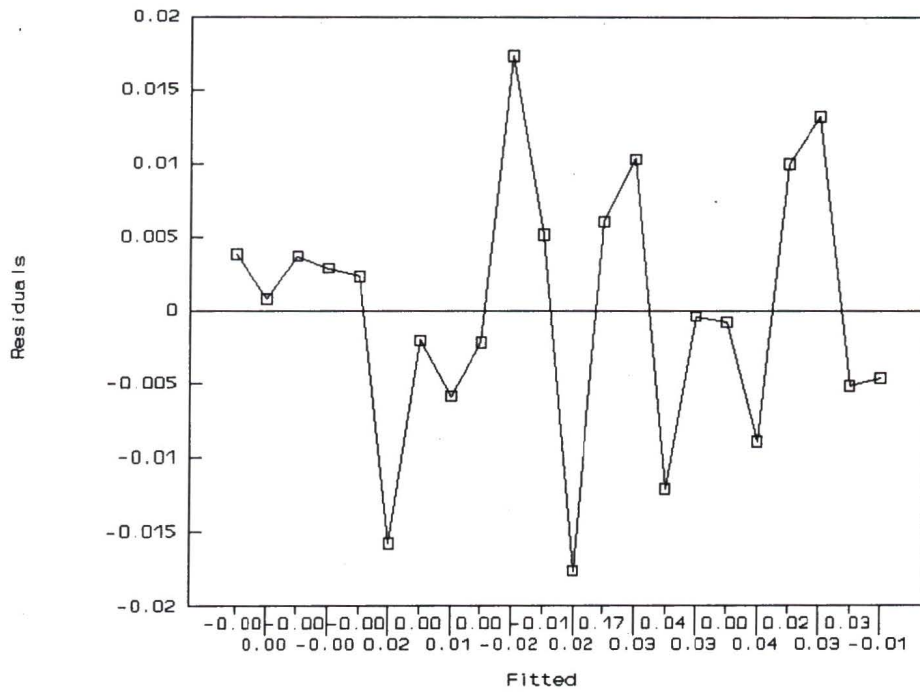
Fitted vs. Residuals

Eq. 2 Wood Industry



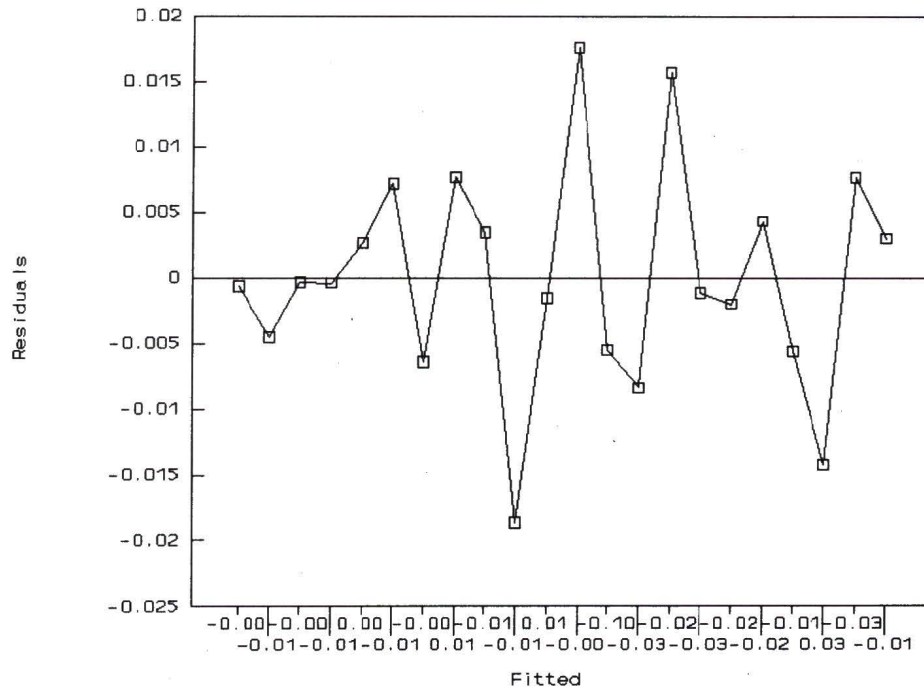
Fitted vs. Residuals

Eq. 1 Furniture and Fixtures Industry



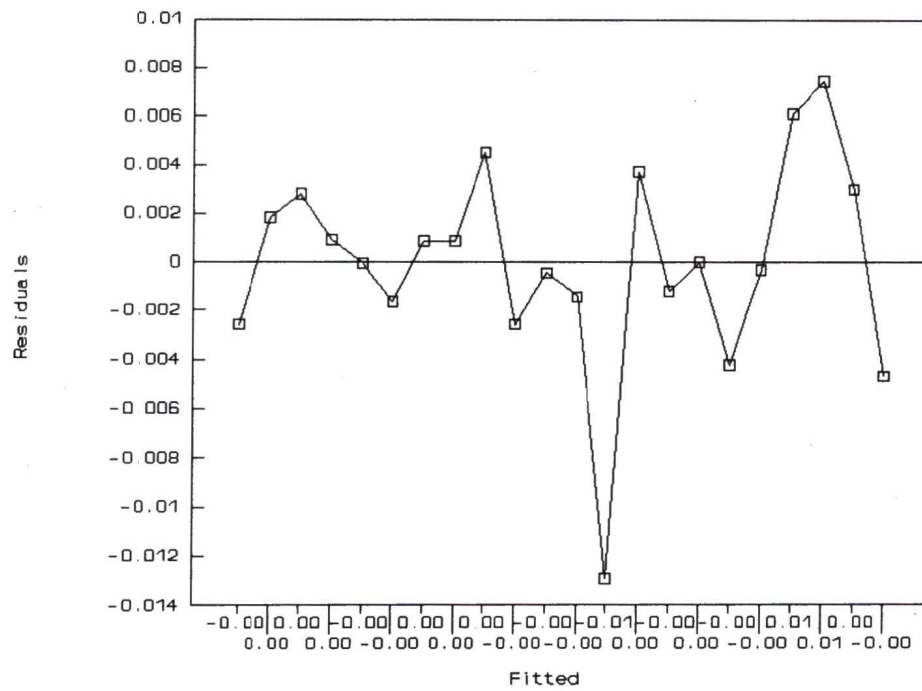
Fitted vs. Residuals

Eq. 2 Furniture and Fixtures Industry



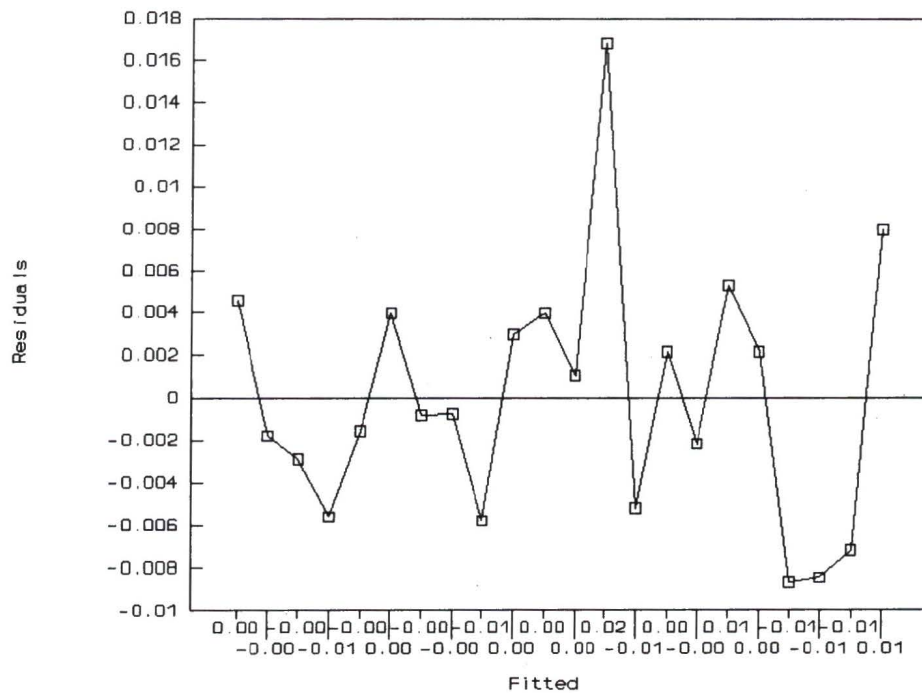
Fitted vs. Residuals

Eq. 1 Paper and Allied Industry



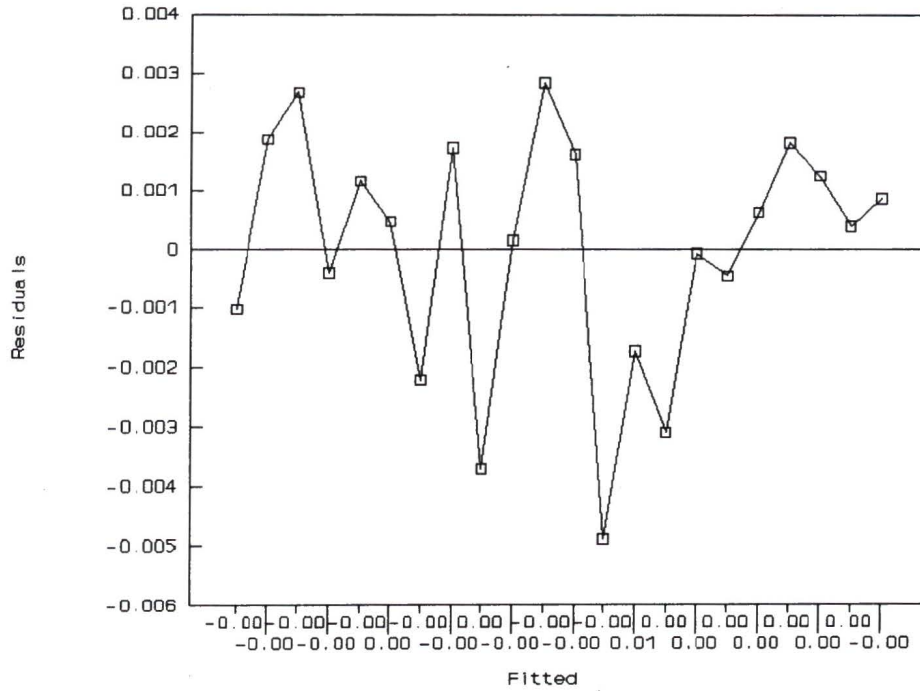
Fitted vs. Residuals

Eq. 2 Paper and Allied Industry



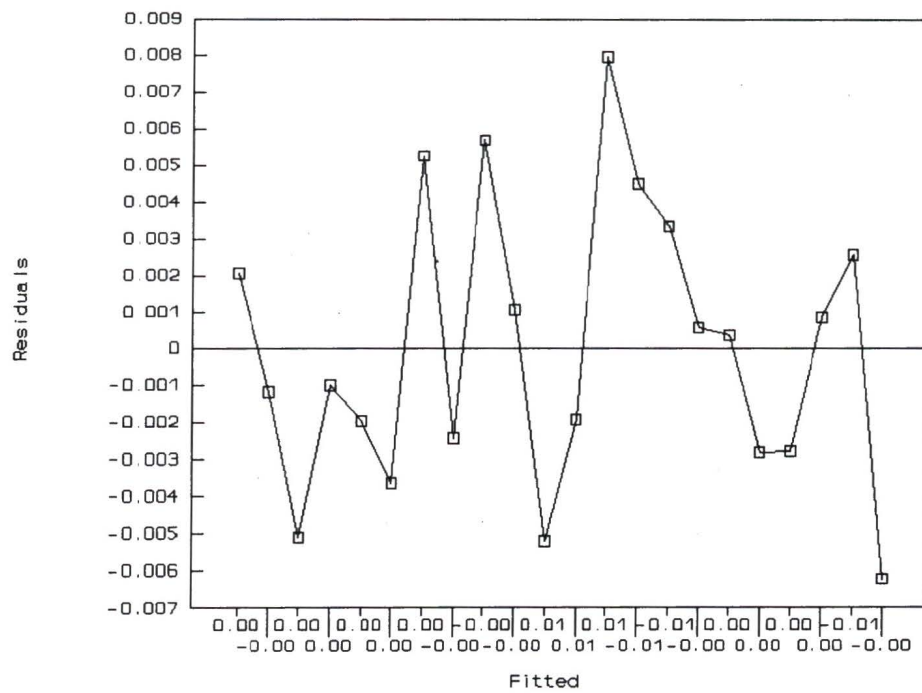
Fitted vs. Residuals

Eq. 1 Primary Metals Industry



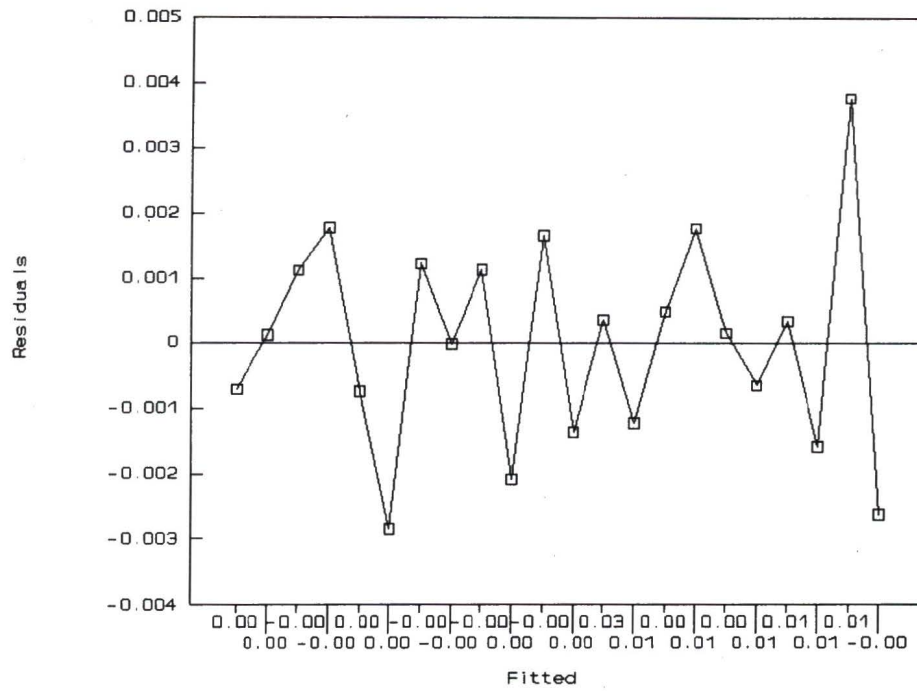
Fitted vs. Residuals

Eq. 2 Primary Metals Industry



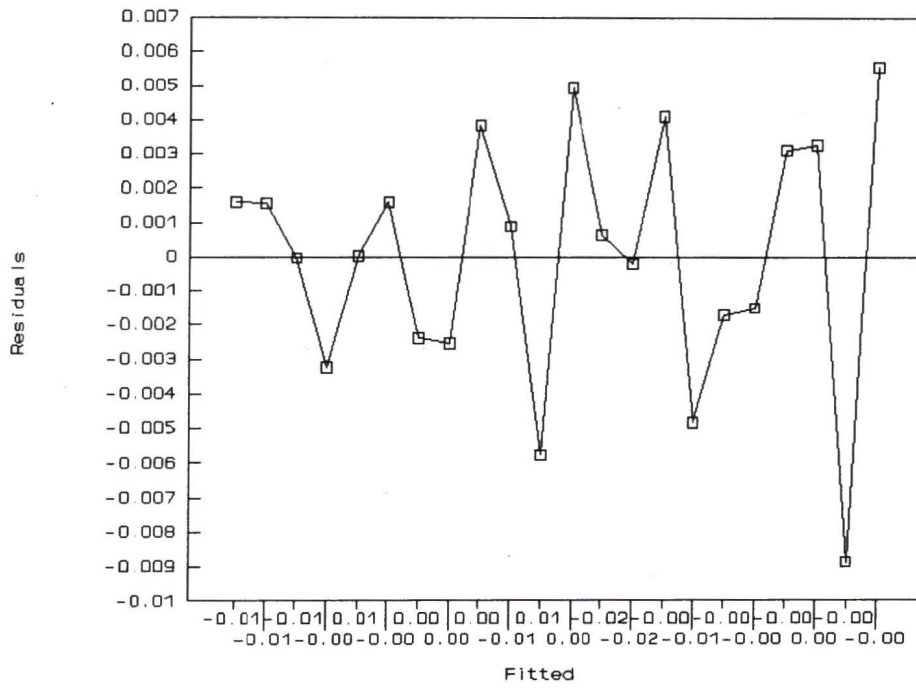
Fitted vs. Residuals

Eq. 1 Metal Fabricating Industry



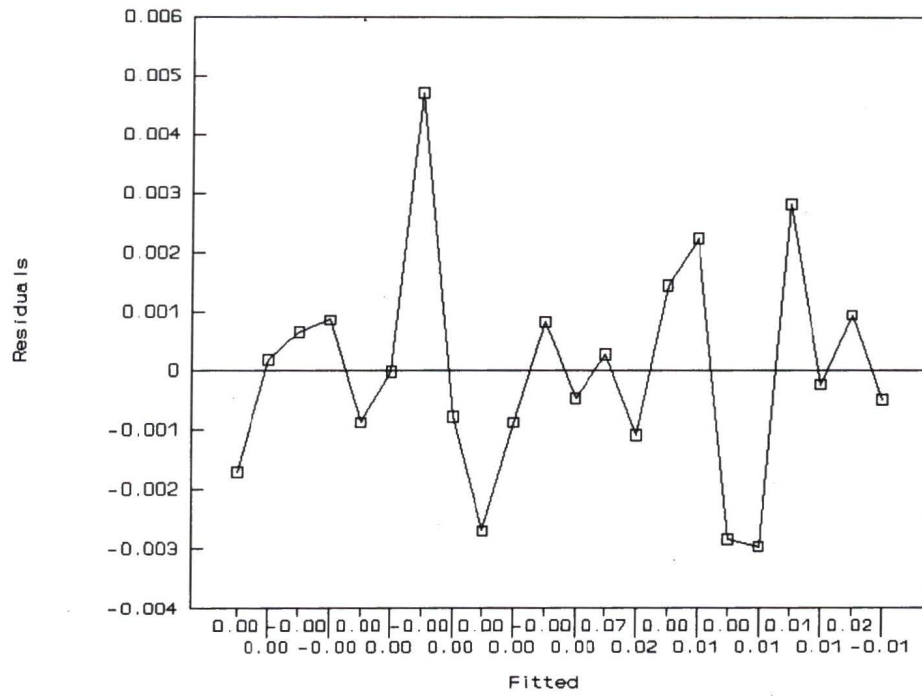
Fitted vs. Residuals

Eq. 2 Metal Fabricating Industry



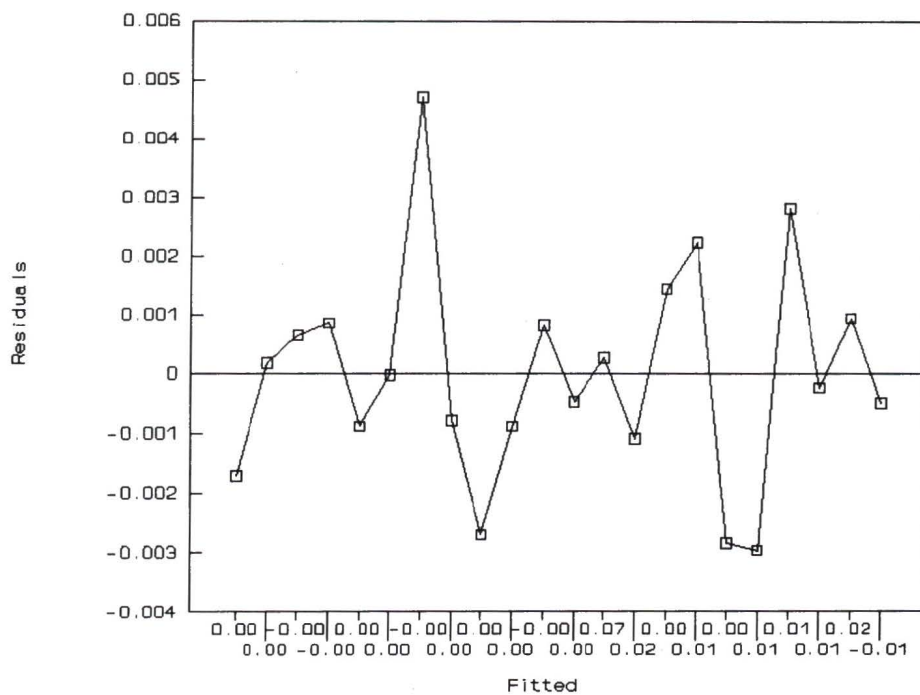
Fitted vs. Residuals

Eq. 1 Machinery Industry



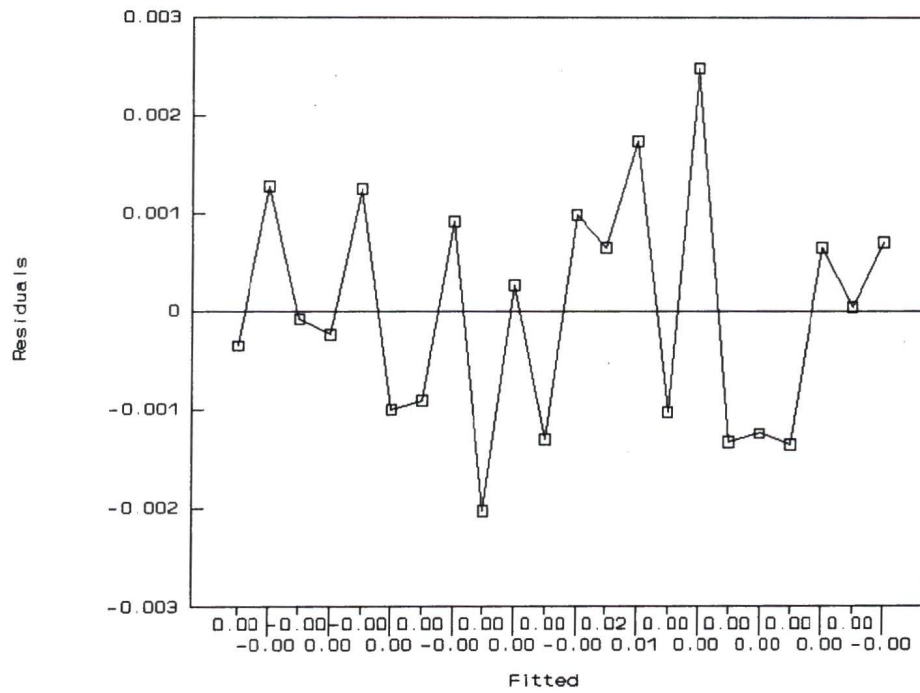
Fitted vs Residuals

Eq. 2 Machinery Industry



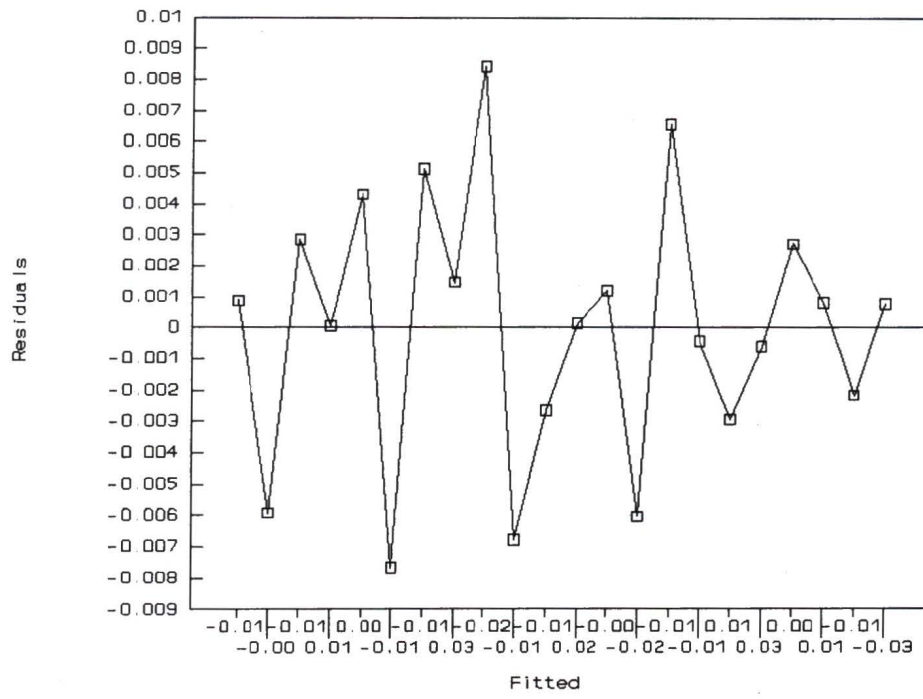
Fitted vs. Residuals

Eq. 1 Transportation Equipment Industry



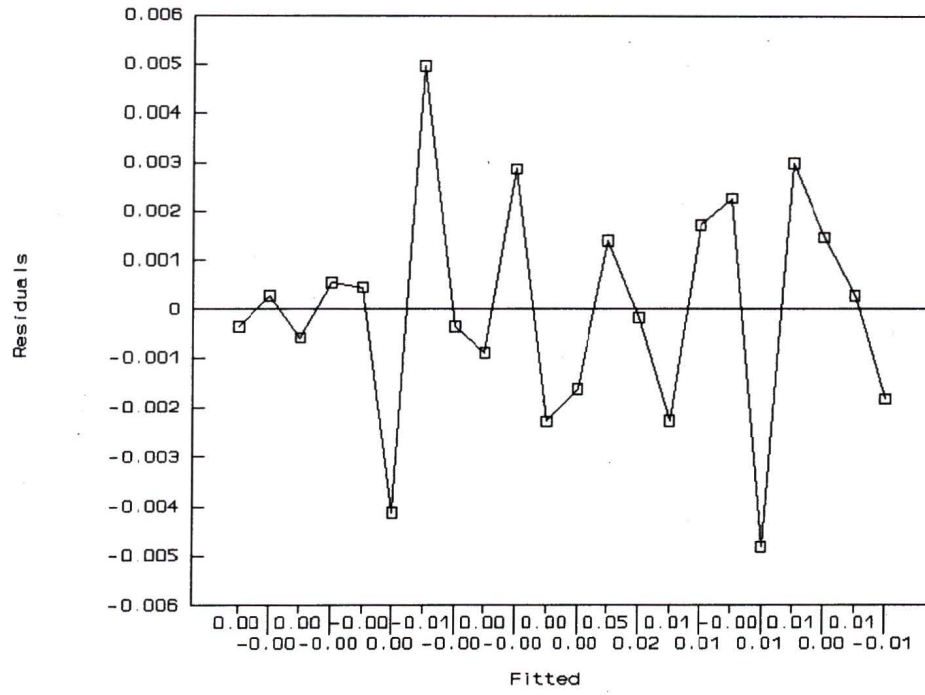
Fitted vs. Residuals

Eq. 2 Transportation Equipment Industry



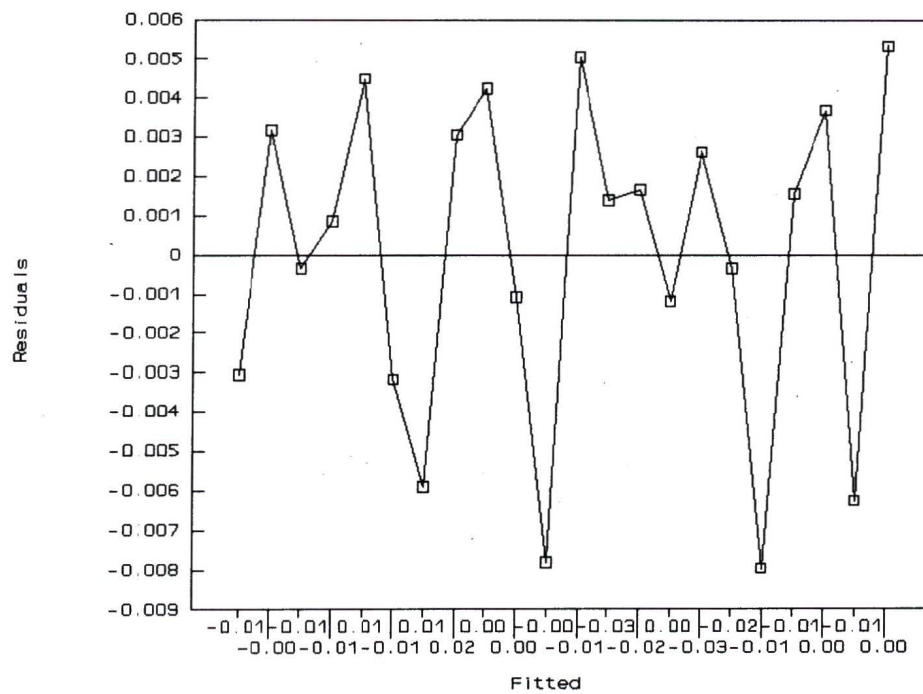
Fitted vs Residuals

Eq. 1 Electrical Products Industry



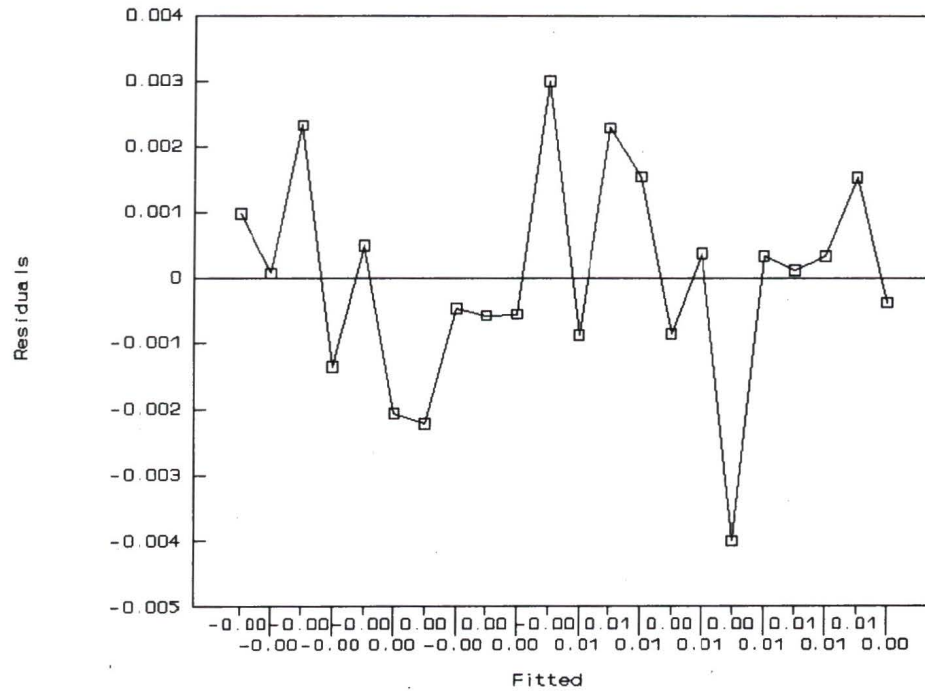
Fitted vs Residuals

Eq. 2 Electrical Products Industry



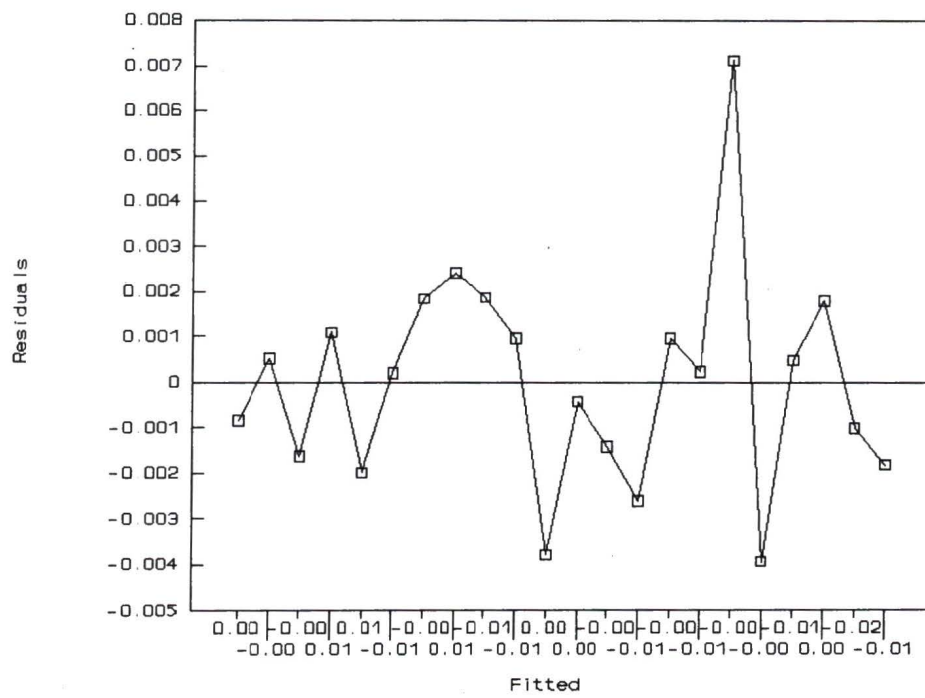
Fitted vs. Residuals

Eq. 1 Non-metallic Mineral Products



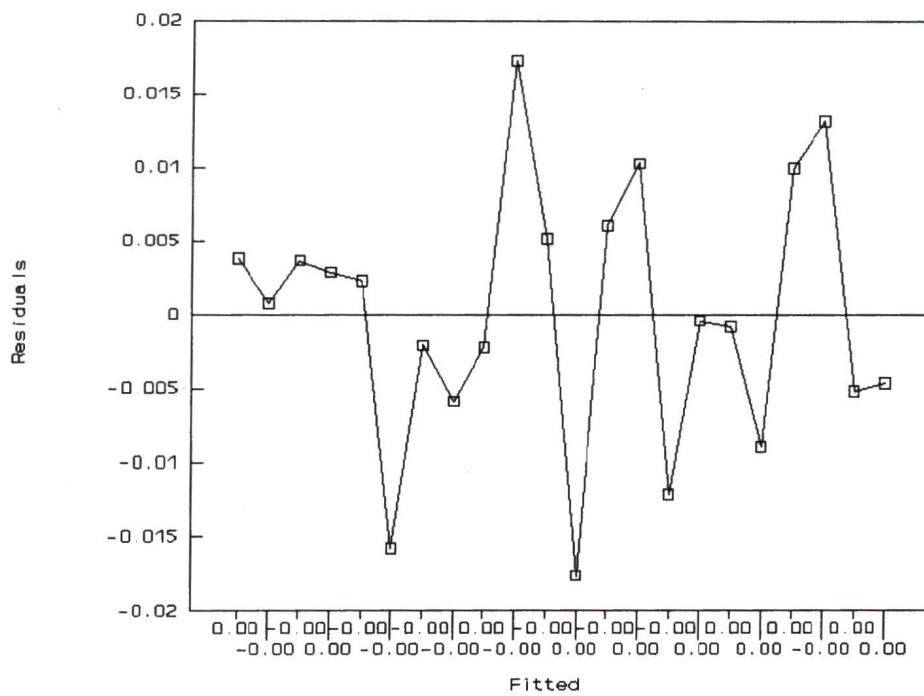
Fitted vs. Residuals

Eq. 2 Non-metallic Mineral Products



Fitted vs. Residuals

Eq. 1 Chemical and Chemical Products



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VITA

Surname: Campbell Given Names: Kevin F.

Place of Birth: Summerside, P.E.I. Date of Birth: 05/15/64

Educational Institutions Attended:

| | |
|------------------------|--------------|
| Acadia University | 1981 to 1983 |
| University of Victoria | 1984 to 1994 |

Degrees Awarded

| | | |
|-------|------------------------|------|
| B.Sc. | University of Victoria | 1989 |
|-------|------------------------|------|

Honours and Awards

| | |
|--|------|
| Acadia University Entrance Scholarship | 1981 |
| Canadian Pacific Scholarship | 1989 |
| The Phillips, Hagar, and North Ltd | |
| Graduate Bursary | 1990 |

Publications:

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Author



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Nov 30 1994
