AN ECONOMETRIC MODEL OF THE DEMAND IN THE CHLORINE AND ALKALI INDUSTRIES

by

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ABSTRACT

This study provides an analysis of the supply and demand balances in the Chlor/Alkali industry. In particular, two models were developed that describe the movement of prices and consumption of chlorine, caustic soda, and soda ash. The first model identifies the income and price elasticities of consumption for each of the chemicals. This model is useful in that it provides a means of assessing the impact that an economic shock (drastic change in GNP) or an industry price shock would have on consumption.

The second model identifies the movements of consumption and price over time using a time series trend analysis. This model is useful because it provides a more accurate means of predicting price and consumption trends with only time as the independent variable. In addition, this model identified the existence of stable and predictable cyclical patterns in consumption and price. These cycles can be used to predict when growth or decline in consumption and prices will reverse.

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CHAPTER 1

INTRODUCTION

The Chlor/Alkali industry consists of three commodity inorganic chemicals that find a variety of uses throughout the chemical industry. These chemicals include:

- Chlorine
- Caustic Soda (Sodium Hydroxide)
- Soda Ash (Sodium Carbonate)

The analysis of the supply and demand of these chemicals is complicated by the way in which their markets interact. In particular, nearly all chlorine and caustic soda are produced simultaneously (co-produced) through the elctrolysis of brine. Chlorine/caustic soda producers must therefore price these chemicals so that they sell in the fixed proportions in which they are produced. Thus, the price of chlorine will be affected by the price of caustic soda and vice versa.

In addition, caustic soda is used primarily as an alkali. There are two chemicals that meet the demand for alkalis which include caustic soda and soda ash. These chemicals compete heavily for the alkali market which makes their closely related. The supply and demand for soda ash will therefore affect the supply and demand of caustic soda.

This paper focuses on an analysis of the supply and demand of these three chemicals and identifies an econometric model that describes their market interactions.

CHAPTER 2

SUMMARY

The purpose of this study was to provide a mathematical explanation of how prices and consumption vary in the chlorine and alkali markets. As previously explained, the co-production nature of chlorine and caustic soda strongly affects how these chemicals are priced and how their consumption varies with price. In addition, soda ash is the prime substitute for caustic soda in the alkali market and its pricing and consumption patterns should be strongly correlated to those of caustic soda. The models that were developed take these interactions into account and, as such, provide a more accurate means of forecasting price and demand in the Chlor/Alkali industry.

2.1 Behavior of Price and Consumption

In this study, two basic models were examined which include:

- An elasticity model that examines income and price elasticities of chlorine, total alkali, and soda ash.
- A time series model that examines the trend of consumption and prices as a function of time only.

2.1.1 Income and Price Elasticities of Consumption

Table 2-1 includes best-fit regression equations that describe the consumption of chlorine, caustic soda, and total alkali. Also included is a best-fit regression equation that relates the price of soda ash to the price of caustic soda. These equations represent a model that describes the entire chlor/alkali industry.

Table 2-1: Difference Model Regression Summary

1960 - 1989	1960 - 1974	1975 - 1989
Chlorine Consumption		
$\Delta\ln(C^{Cl}_t) = -0.048 + 2.4\,\Delta\ln(GNP_t) - 0.18\,\Delta\ln(P^{Cl}_{t-2})$	$\Delta\ln(C^{Cl}_t) = -0.017 + 1.2\,\Delta\ln(GNP_t)$	$\Delta\ln(C^{Cl}_t) = -0.079 + 3.0\,\Delta\ln(GNP_t) - 0.14\,\Delta\ln(P^{Cl}_{t-2})$
R^2adjusted = 60.6%	R^2adjusted = 28.6%	R^2adjusted = 76.7%
Alkali Consumption		
$\Delta\ln(C^{Alk}_t) = -0.029 + 1.7\,\Delta\ln(GNP_t) - 0.092\,\Delta\ln(P^{CS}_t)$	$\Delta\ln(C^{Cl}_t) = 0.0036 + 1.1\,\Delta\ln(GNP_t) - 0.18\,\Delta\ln(P^{CS}_t)$	$\Delta\ln(C^{Cl}_t) = -0.068 + 2.5\,\Delta\ln(GNP_t) - 0.16\,\Delta\ln(P^{CS}_{t-3})$
R^2adjusted = 50.2%	R^2adjusted = 51.6%	R^2adjusted = 59.0%
Soda Ash Consumption		
$\Delta\ln(C^{SA}_t) = -0.026 + 1.2\Delta\ln(GNP_t) - 0.077\,\Delta\ln(P^{CS}_{t-4}) - 0.068$ (1967 Shock)	$\Delta\ln(C^{SA}_t) = -0.009 + 0.88\,\Delta\ln(GNP_t) - 0.078\,\Delta\ln(P^{CS}_{t-1}) - 0.071$ (1967 Shock)	$\Delta\ln(C^{Cl}_t) = -0.038 + 1.6\,\Delta\ln(GNP_t) - 0.070\,\Delta\ln(P^{CS}_{t-4}) - 0.051$ (1984 Shock)
R^2adjusted =72.1%	R^2adjusted = 81.7%	R^2adjusted = 85.7%
Soda Ash Price		
$\Delta\ln(P^{SA}_t) = -0.0006 + 0.21\,\Delta\ln(P^{CS}_{t-1}) + 0.35\,\Delta\ln(P^{CS}_{t-5})$	$\Delta\ln(P^{SA}_t) = -0.035 - 0.72\,\Delta\ln(P^{CS}_{t-4})$	$\Delta\ln(P^{SA}_t) = -0.0096 + 0.19\,\Delta\ln(P^{CS}_{t-1}) + 0.38\,\Delta\ln(P^{CS}_{t-5})$
R^2adjusted =38.0%	R^2adjusted = 45.2%	R^2adjusted = 42.7%

Shock variables simply reduce the estimated change in the natural logarithm of consumption by the coefficient in the year of the shock.

The coefficients of the variables represent the elasticities of consumption which indicate the percentage change in consumption that will result from a one percent change in each variable. These elasticities are summarized in Table 2-2.

Table 2-2: Elasticities of Chlorine, Total Alkali, and Soda Ash Consumption

	1960 to 1989	1960 to 1974	1960 to 1989
Chlorine Consumption			
Income Elasticity	2.4	1.2	3.0
Current Price Elasticity	0.0	0.0	0.0
Lagged Price Elasticity /Years Lag	-0.18/2	0.0	-0.14/2
Alkali Consumption			
Income Elasticity	1.7	1.1	2.5
Current Price Elasticity	-0.09	-0.18	0.0
Lagged Price Elasticity /Years Lag	0.0	0.0	-0.16/3
Soda Ash Consumption			
Income Elasticity	1.2	0.9	1.6
Current Price Elasticity	0.0	0.0	0.0
Lagged Price Elasticity/Years Lag	-0.08/4	-0.08/1	-0.07/4

Overall, the income elasticity of chlorine consumption has been slightly greater than that of total alkali consumption over the thirty year study period (1960 to 1989). More interestingly, the income elasticities of both chlorine and total alkali consumptions have more than doubled from their levels during

1960 to 1974 to their levels during 1975 to 1989. The income elasticity of soda ash has been consistently less than that of both chlorine and total alkali and has also nearly doubled from its level during 1960 to 1974 to its level during 1975 to 1989.

The large increase in income elasticity of all chemicals suggests that consumption has become more of a function of the overall level of the economy. During 1960 to 1974 the demand for all three chemicals could be described as consistently growing because of an increase in the uses for these chemicals. This growth, although linked somewhat to the overall economy, depended more on the increases in use. During 1975 to 1989, growth diminished as the industry matured. As such, demand became less of a function of growth and depended more strongly on the overall economy.

Price elasticities of chlorine and alkali consumption have been similar in magnitude throughout the period while chlorine consumption has generally reacted two to three years earlier than alkali and soda ash consumption to changes in price. All of these price elasticities are relatively small and indicate that a 1% change in price will only affect consumption by between 0.07 and 0.18%.

In general, the price elasticity of soda ash has been about half that of either chlorine or total alkali. With its strong export markets, soda ash has maintained more growth than either chlorine or caustic soda. This steadily increasing export demand has been relatively price insensitive and has therefore lowered the overall price sensitivity of soda ash.

Finally, soda ash and caustic soda prices are indeed closely related. As shown in Table 2-1, the price of soda ash can be related to past prices of caustic soda. This strong interaction is a result of the competition that exists between the two chemicals as they make up nearly all of the alkali market.

2.1.2 Trends of Price and Consumption

Tables 2-3 and 2-4 provide best-fit regression equations that describe consumption and prices in the chlor/alkali industry based solely on trends. These time series regressions assume that the demand and prices for chlorine, caustic soda, and soda ash follow some cycle that can be predicted as a function of time without other predictor variables.

One explanation for these cycles is as follows:

> A low price will lead to a high demand. High demand will, in turn, lead to a high price which will then lead to a reduction in demand. Finally, the reduced demand will create an over-capacity in the industry and producers will lower their prices to start the cycle all over again.

The times series model assumes that this pattern occurs with some regular frequency over a certain number of years.

Annual chlorine consumption, alkali consumption, and soda ash consumption were all strongly related to their levels in the previous year (lagged consumption) with elasticities ranging from 0.9 to 1.0 for the period 1960 to 1974. This relationship, however, became weaker during 1975 to 1989 for all three chemicals with the elasticity falling to zero for chlorine, 0.45 for alkali, and 0.25 for soda ash.

Table 2-3 Time Series Regressions of Consumption

1960 - 1989	1960 - 1974	1975 - 1989
Chlorine Consumption		
$\ln(C^{Cl}_t) = 0.64 + 0.93 \ln(C^{Cl}_{t-1})$ -0.026 (5 Yr Cycle Factor_t) -0.21 (1975 Shock) -0.20 (1982 Shock)	$\ln(C^{Cl}_t) = 0.17 + 0.99 \ln(C^{Cl}_{t-1})$ -0.038 (5.5 Yr Cycle Factor_t)	$\ln(C^{Cl}_t) = 9.22$ 0.082 (4.5 Yr Cycle Factor_t) -0.12 (1982 Shock) $+0.10$ (1984 Shock)
Reference Year = 1960	Reference Year = 1960	Reference Year = 1961
R^2adjusted = 97.2%	R^2adjusted = 98.4%	R^2adjusted = 90.1%
Alkali Consumption		
$\ln(C^{Alk}_t) = 1.00 + 0.89 \ln(C^{Alk}_{t-1})$ -0.031 (5.5 Yr Cycle Factor_t) -0.17 (1975 Shock)	$\ln(C^{Alk}_t) = 0.38 + 0.96 \ln(C^{Alk}_{t-1})$ -0.026 (5.5 Yr Cycle Factor_t)	$\ln(C^{Alk}_t) = 5.2 + 0.45 \ln(C^{Alk}_{t-1})$ -0.041 (5.5 Yr Cycle Factor_t) -0.17 (1975 Shock)
Reference Year = 1960	Reference Year = 1960	Reference Year = 1960
R^2adjusted = 94.2%	R^2adjusted = 97.2%	R^2adjusted = 57.9%
Soda Ash Consumption		
$\ln(C^{SA}_t) = 1.29 + 0.86 \ln(C^{SA}_{t-1})$ -0.017 (5.5 Yr Cycle Factor_t) -0.082 (1975 Shock)	$\ln(C^{SA}_t) = 1.0 + 0.89 \ln(C^{SA}_{t-1})$ -0.016 (4 Yr Cycle Factor_t)	$\ln(C^{SA}_t) = 6.61 + 0.25 \ln(C^{SA}_{t-1})$ -0.037 (6 Yr Cycle Factor_t) -0.062 (1975 Shock)
Reference Year = 1960	Reference Year = 1960	Reference Year = 1960
R^2adjusted =89.0%	R^2adjusted = 93.2%	R^2adjusted = 64.1%

N Yr Cycle Factor_t = Cosine(π/N*(Year_t - Reference Year))
Shock variables reduce the estimated change in the natural logarithm of consumption by the coefficient in the year of the shock.

Table 2-4: Time Series Regressions of Real Prices

1960 - 1989	1960 - 1974	1975 - 1989
Chlorine Price $\ln(P^{Cl}_t) = -0.43 + 0.91 \ln(P^{Cl}_{t-1}) + 0.074$ (4 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 75.8%	$\ln(P^{Cl}_t) = 0.73 + 0.85 \ln(P^{Cl}_{t-1}) + 0.042$(9 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 96.0%	$\ln(P^{Cl}_t) = 1.1 + 0.76 \ln(P^{Cl}_{t-1}) + 0.13$ (4 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 67.6%
Caustic Soda Price $\ln(P^{CS}_t) = 0.96 + 0.80 \ln(P^{CS}_{t-1}) - 0.010$ (4 Yr Cycle Factor$_t$) $+0.39$ (1975 Shock) Reference Year = 1960 R^2adjusted = 63.5%	$\ln(P^{CS}_t) = 1.24 + 0.74 \ln(P^{CS}_{t-1}) - 0.084$(4 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 73.7%	$\ln(P^{CS}_t) = 0.80 + 0.84 \ln(P^{CS}_{t-1}) - 0.13$ (4 Yr Cycle Factor$_t$) $+ 0.40$ (1975 Shock) Reference Year = 1960 R^2adjusted = 51.5%
ECU Price $\ln(P^{ECU}_t) = 1.9 + 0.67 \ln(P^{ECU}_{t-1}) + 0.049$ (8 Yr Cycle Factor$_t$) $+0.20$ (1975 Shock) Reference Year = 1960 R^2adjusted =82.5%	$\ln(P^{ECU}_t) = 1.63 + 0.71 \ln(P^{ECU}_{t-1}) + 0.051$ (8 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 75.2%	$\ln(P^{ECU}_t) = 2.1 + 0.62 \ln(P^{ECU}_{t-1}) + 0.052$ (8 Yr Cycle Factor$_t$) $+0.21$ (1975 Shock) Reference Year = 1960 R^2adjusted = 78.1%
Soda Ash Price $\Delta\ln(P^{SA}_t) = -0.0006 + 0.21 \Delta\ln(P^{CS}_{t-1}) + 0.35 \Delta\ln(P^{CS}_{t-5})$ R^2adjusted =38.0%	$\Delta\ln(P^{SA}_t) = -0.034 - 0.72 \Delta\ln(P^{CS}_{t-4})$ R^2adjusted = 45.2%	$\Delta\ln(P^{SA}_t) = -0.0096 + 0.19 \Delta\ln(P^{CS}_{t-1}) + 0.38 \Delta\ln(P^{CS}_{t-5})$ R^2adjusted = 42.7%

N Yr Cycle Factor$_t$ = Cosine(π/N*(Year$_t$ - Reference Year))
Shock variables reduce the estimated change in the natural logarithm of consumption by the coefficient in the year of the shock.

The consumption of all three chemicals also exhibited a predictable fluctuation around this lagged relationship that cycled over approximately five years for chlorine, 5.5 years for alkali, and 5.5 to 6 years for soda ash. Consumptions of chlorine, alkali, and soda ash all have become less dependent on lagged consumption and more dependant on a stable cycle. This indicates that the entire Chlor/Alkali industry has matured and that growth has virtually stopped.

Finally, economic shocks proved to significantly affect the variation of consumption of chlorine, alkali, and soda ash from the stable cycles. Chlorine was the most sensitive and was affected by shocks in 1975, 1982, and 1984. Total alkali and soda ash were somewhat less sensitive and responded with statistical significance to only the 1975 shock.

Since long-term growth has virtually stopped, forecasts for consumption and price are best made using the time series trends rather than the elasticity model. The elasticity model, however, provides a useful tool for predicting responses of consumption to shocks in income or prices that are outside of the normal trend.

2.2 Forecasts of Price and Consumption

As previously stated, the time series model is the simplest model to use to project real price trends because it does not require the forecasting of other indicator variables such as GNP. In addition, it provides a more accurate picture of the trends that are present in the industry because the industry has become more dependent on the supply/demand cycle and less dependent on growth.

2.2.1 Projected Price Trends

Using the time series model, the real prices of caustic soda, chlorine, the ECU, and soda ash were calculated and compared to historic prices. In addition, predicted prices were projected out to 1994 to provide a forecast of the trends in the industry. Table 2-4 provides a summary of these price projections.

Table 2-4: Real Price Forecasts for Chlorine, Caustic Soda, ECU, and Soda Ash

	Real Price, 1982 $*				
	1990	1991	1992	1993	1994
Chlorine	87	100	116	125	120
Caustic Soda	156	138	120	110	113
ECU	273	285	294	298	293
Soda Ash	62	57	54	63	64

*Conversion to nominal prices can be made using the Chemical Industry Producer Price Index, from the Economic Report of the President to Congress

The highlights of these projections include:

- The real price of chlorine will fall again in 1990 and then rebound through 1993, peaking at approximately $125/ST (1982 dollars).
- The real caustic soda price will start to fall and will hit a low of around $110/ST (1982 dollars) in 1993.
- The ECU real price will continue to rebound over the next four years and should peak at approximately $298/ST (1982 dollars) by 1993.

- Comparing the forecasts for the price of caustic soda and the price of chlorine shows that by 1992, the prices of chlorine and caustic soda will be roughly the same. By 1993, the price of chlorine may actually surpass that of caustic soda for one to two years.

- The real price of soda ash will decline over the next two to three years to approximately $54/ST (1982 dollars) and will then rebound through 1994 to roughly $64/ST. In general, the real price of soda ash will continue to slowly cycle between $55/ST and $65/ST as the supply/demand balance for alkali cycles in response.

2.2.2 Projected Consumption Trends

Table 2-5 includes a summary of the predictions of the consumptions of chlorine, caustic soda, soda ash, and total alkali.

Table 2-5: Consumption Forecasts for Chlorine, Caustic Soda, Soda Ash, and Total Alkali

	Annual Consumption, M-ST				
	1990	1991	1992	1993	1994
Chlorine	10,200	9,800	9,300	9,300	9,600
Caustic Soda	10,700	10,200	9,700	9,400	9,300
Soda Ash	7,300	7,300	7,200	7,000	6,900
Total Alkali	12,300	12,000	11,600	11,200	11,000

The highlights of these predictions include:

- Chlorine consumption will fall over the next few years and by 1993 should decline to roughly 9,200 M-ST by 1992.

- Caustic soda consumption will continue to decline over the next few years and by 1994, should fall to approximately 9,300 M-ST per year.

- Soda ash consumption will remain fairly stable over the next couple of years at 7,300 M-ST and will then fall to approximately 6,900 M-ST by 1994.

- Total alkali consumption showed signs of decline in 1989 and should continue to decline for the next four years, falling to approximately 11,000 M-ST by 1994.

- The recession will potentially worsen all of these declines depending upon its magnitude.

These models rely on a mathematical trend that was evident in the past. They do not specifically address shocks to the industry such as drastic changes in regulations that may severely impact demand or costs of production. In addition, although the model for consumption does not specifically include the effect of prices on consumption, consumption can be statistically predicted with price and vice versa so that their effects can be separated out of the equation. The effect of an exogenous price or demand shock can be evaluated using the differenced regression model, summarized in Table 2-1, which provides estimates of the price and income elasticities of consumption.

CHAPTER 3

TECHNOLOGY OF THE CHLOR/ALKALI INDUSTRY

3.1 Chlorine/Caustic Soda Technology

Brine electrolysis is the basic chemical reaction by which most chlorine and caustic soda are produced. In 1987 nearly 97% of U.S. chlorine production and 100% of U.S. caustic soda production was through this process.[1] The chemical reaction used in this process is represented as follows:

$$\underset{\text{Sodium Chloride (Salt Water)}}{2Na^+ + 2Cl^-} + \underset{\text{Water}}{2H_2O} \xrightarrow{\text{Electricity}} \underset{\text{Chlorine}}{Cl_2} + \underset{\text{Hydrogen}}{H_2} + \underset{\text{Sodium Hydroxide}}{2NaOH}$$

The sodium and chloride inputs are provided by brine (salt water). Chlorine is produced as a gas and is either sold as a gas or compressed and sold as a liquid. Sodium hydroxide is produced from this process in solution. Typically, this solution is then concentrated though evaporation to a 50% solution or dried completely to a solid (97% sodium hydroxide) and sold. Hydrogen, while it has value as a raw material in the chemical industry, is usually burned as a fuel to provide heat to the sodium hydroxide concentrators.

Based on molecular weights, and 100% efficient operation, 1.65 tons of salt will yield 1 ton of chlorine and 1.13 tons of sodium hydroxide. Typical

[1]Marilynne Smart, Rice, G., Leder, A., Schlegel, W., Nakamura, E., "Chemical Economics Handbook Marketing Report - Chlorine/Sodium Hydroxide", Chemical Economics Handbook, SRI International, 1989, 733.1000 H.

production has yielded chlorine and sodium hydroxide in the ratio of 1:1.1. This combination of 1 ton of chlorine with 1.1 tons of sodium hydroxide is called an Electrochemical Unit (ECU). The economic return on this production process is calculated by comparing the market price of an ECU with the total production costs.

Three processes use brine electrolysis to produce chlorine and caustic soda. These include:

- Diaphragm Cell Process
- Membrane Cell Process
- Mercury Cell Process

Diaphragm Cell Process

The diaphragm cell process is the primary method of chlorine/caustic soda production the U.S. providing nearly 80% of the production.[2] A typical diaphragm cell consists of two chambers, an anode chamber and a cathode chamber. In this process, brine flows to the anode (positively charged) compartment of the cell where chloride ions are converted to chlorine gas. Sodium ions then flow through the diaphragm to the cathode (negatively charged) compartment where water reacts on the cathode to form hydrogen gas and hydroxide ions, leaving sodium hydroxide in solution. The diaphragm separates the chambers to prevent the brine solution from mixing with the sodium hydroxide (caustic soda). It is, however, not perfect and some mixing does occur. The resulting solution is then partially evaporated

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[2] Ibid, 733.1000 H.

to precipitate salt which increases both the purity and concentration of the caustic soda solution.

Membrane Cell Process

The membrane cell process provides roughly 5% of the chlorine/caustic soda production in the U.S.[3] This process is essentially the same as the diaphragm process except that a specialized membrane is used instead of the diaphragm. The membrane is porous to only sodium and prevents virtually all mixing between the brine and sodium hydroxide solutions. As a result, this process provides a purer solution of caustic soda.

Membrane cell technology is the newest of the three primary chlorine/caustic soda production technologies and is slowly replacing the other two technologies.

Mercury Cell Process

The mercury cell process is a two-step chemical reaction which includes an intermediate reaction with mercury. The overall chemical reaction is as follows:[4]

$$2Na^{+} + 2Cl^{-} + \underset{\text{Mercury}}{2Hg} \longrightarrow \underset{\text{Mercury Amalgam}}{2Hg\text{-}Na} + Cl_2$$

$$2Hg\text{-}Na + 2H_2O \longrightarrow 2NaOH + H_2 + 2Hg$$

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[3]Ibid, 733.1000 I.
[4]Ibid, 733.1000 J.

The first reaction occurs in one chamber where the anode releases chlorine and the mercury forms an amalgam with sodium. This mercury amalgam then flows to a second compartment (decomposer) where the second reaction occurs to release sodium hydroxide, hydrogen, and mercury. This separation prevents the brine from mixing with the caustic soda solution, thereby giving a high purity product.

Environmental concerns over the disposal of waste mercury have led producers to move away from the mercury process. Plants using this process are being shut down in favor of plants using diaphragm and membrane cell technologies. Currently, approximately 15% of the U.S. chlorine/caustic soda capacity consists of mercury cell technology.

Other Chlorine-Producing Technologies

There are several other technologies that are used to provide approximately 3% of the U.S. production of chlorine. These include:[5]

- Chlorine from hydrogen chloride
- Chlorine as a by-product of metal production
- Chlorine co-produced with potassium hydroxide
- Chlorine as a by-product of potassium nitrate production

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[5]Ibid, 733.1000 K

Other Sodium Hydroxide Production

The only significant alternative technology for the production of caustic soda is the "lime soda" process.[6] In this process, sodium carbonate reacts with calcium oxide or calcium hydroxide (lime) to yield sodium hydroxide. The chemical reaction is as follows:

$Ca(OH)_2$	+	Na_2CO_3	------>	$CaCO_3$	+	2NaOH
Lime		Sodium Carbonate (Soda Ash)		Calcium Carbonate		Caustic Soda

The significance of this process is that it provides a means for soda ash to compete more directly with caustic soda. Today, most of the competition between soda ash and caustic soda is for processes that can use either chemical directly. The lime soda process, however, allows soda ash to compete for those processes that require caustic soda as the alkali source.

Manufacturing Costs

Manufacturing costs for the three different processes will vary based on the individual plant. The percentage breakdown of cost components is similar for each type of operation. Typical cost components for the three operations are given in Table 3-1.

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[6] Ibid, 733.1000 L

Table 3-1 Chlorine/Caustic Soda Manufacturing Cost Breakdown

	Diaphragm	Membrane	Mercury
Variable Costs			
Raw Materials and Supplies	10.9	14.3	11.6
Utilities	39.8	35.9	41.3
Fixed Costs			
Labor	6.8	6.8	6.4
Depreciation and Overhead	34.5	34.9	32.8
General and Administrative, Sales and Research	8.0	8.1	7.9
	----	----	----
Total	100.0%	100.0%	100.0%

Source: Smart, M., Rice, G., Leder, A., Schlegel, W., Nakamura, E., "Chemical Economics Handbook Marketing Report - Chlorine/Sodium Hydroxide", Chemical Economics Handbook, SRI International, 1989, 733.1000 M.

Raw materials and supplies consists primarily of the salt used in the process while utilities includes basically the energy used to electrolyze the salt and the heat used to concentrate the sodium hydroxide solution. Of the variable costs of production, utilities is by far the largest component comprising between 70% and 80% of the total. Thus, these facilities are often located based on the availability of a relatively inexpensive power supply.

3.2 Soda Ash Technology

Soda ash (sodium carbonate) can be produced either synthetically or naturally. Although synthetic production of soda ash had been popular at one time in the U.S., natural production has since become far less costly and has completely replaced synthetic production. The last U.S. plant producing soda ash synthetically was closed in 1986.[7]

Natural Production of Soda Ash

Soda ash is found naturally in a number of materials, the most prevalent being a naturally hydrated sodium sesquicarbonate (trona).[8] In the U.S, nearly all trona that is mined for soda ash production is found near Green River, Wyoming. About 1.8 tons of trona are required to produce 1 ton of soda ash.

There are two operations that can be used to convert trona to soda ash which include the monohydrate process and the trona process.[9] In the monohydrate process, trona is decomposed by heat to generate sodium carbonate, water, and carbon dioxide. The resulting material is then dissolved in water to remove any insoluble impurities. The sodium carbonate solution is then concentrated to precipitate sodium carbonate monohydrate, leaving behind the more soluble impurities. The sodium carbonate monohydrate is then heated to remove the hydrate, leaving "dense" sodium carbonate (soda ash). Dense soda ash has a bulk density of 60 to 66 pounds per cubic foot.

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[7]Economic Commission for Europe, Market Trends for Selected Chemical Products 1960 - 1985 and Prospects to 1989, Vol.1, United Nations, 1987, 84

[8]F. Alan Ferguson, Callison, S.L., Shimosato, J., and Garnett, A., "Chemical Economics Handbook Product Review - Sodium Carbonate and Sodium Bicarbonate", Chemical Economics Handbook, SRI International, 1984, 733.2000 D

[9]Ibid, 733.2000 D

In the trona process, trona is dissolved in water leaving behind the insoluble impurities and a solution of sodium sesquicarbonate. This solution is then concentrated to precipitate sodium sesquicarbonate, which is decomposed with heat to yield a "light" soda ash, water, and carbon dioxide. Light soda ash has a density of 32 to 39 pounds per cubic foot.

An alternate source of soda ash is found in brines containing high levels of sodium carbonate. In the U.S. the only operations producing sodium carbonate from brines are found at Searles Lake, California.

Synthetic Production of Soda Ash

The Solvay process is the primary synthetic process for producing soda ash.[10] Through a multi-step chemical process, calcium carbonate (limestone) and sodium chloride (salt) are converted into soda ash and calcium chloride. The overall reaction is:

$$CaCO_3 + 2NaCl \text{ ------> } Na_2CO_3 + CaCl_2$$

This process was prevalent in the U.S. up until 1973 at which point natural production became the dominant technology. By 1986, synthetic production had essentially been completely replaced by natural production in the U.S.

3.3 Alkali Technology

Alkali (Na_2O) chemicals in the U.S. consist primarily of caustic soda and soda ash. Both of these chemicals are a good sources of Na_2O as both contain sodium and oxygen. The use of soda ash versus that of caustic soda can be

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[10]Ibid, 733.2000 F

compared by comparing the alkali contents of each. These alkali contents can be calculated as follows:

Chemical	Alkali Equivalent
1 ton of Caustic Soda	0.76 tons Alkali
1 ton of Soda Ash	0.58 tons Alkali

When a chemical process only requires a source of sodium ion, soda ash is typically the chemical of choice because it is has a relatively lower cost per unit of alkali (Na_2O). On the other hand, when both a sodium source and a high alkalinity are required, caustic soda is preferred. In addition, soda ash is only supplied in solid form while caustic soda can be supplied in liquid form. Many users of alkali find it more economical to use a liquid form of alkali because it is easier to handle and process.

CHAPTER 4

SUPPLY/DEMAND

Data of the supply and demand of chlorine, caustic soda, and soda ash were collected from several available public sources. These sources consist of compilations of government statistics and industry surveys. Overall, the data is believed to be accurate to within 2%. Values for changes in inventory, however, may have high margins of error. These values, though, represent only a small fraction of total consumption in any given year.

4.1 Chlorine Supply and Demand

Table 4-1 lists the components of chlorine supply and demand from 1960 to 1989. Figure 4-1 provides a plot of this data. During the thirty years of study, chlorine production increased from 4,637 thousand Short Tons (M-ST) to 11,832 M-ST with an average growth rate of 3.3% per year. Capacity has also grown, but not always in step with production. Utilization has therefore fluctuated throughout the period, typically at around 90% but dropping to as low as 70 percent and as high as 97 percent.

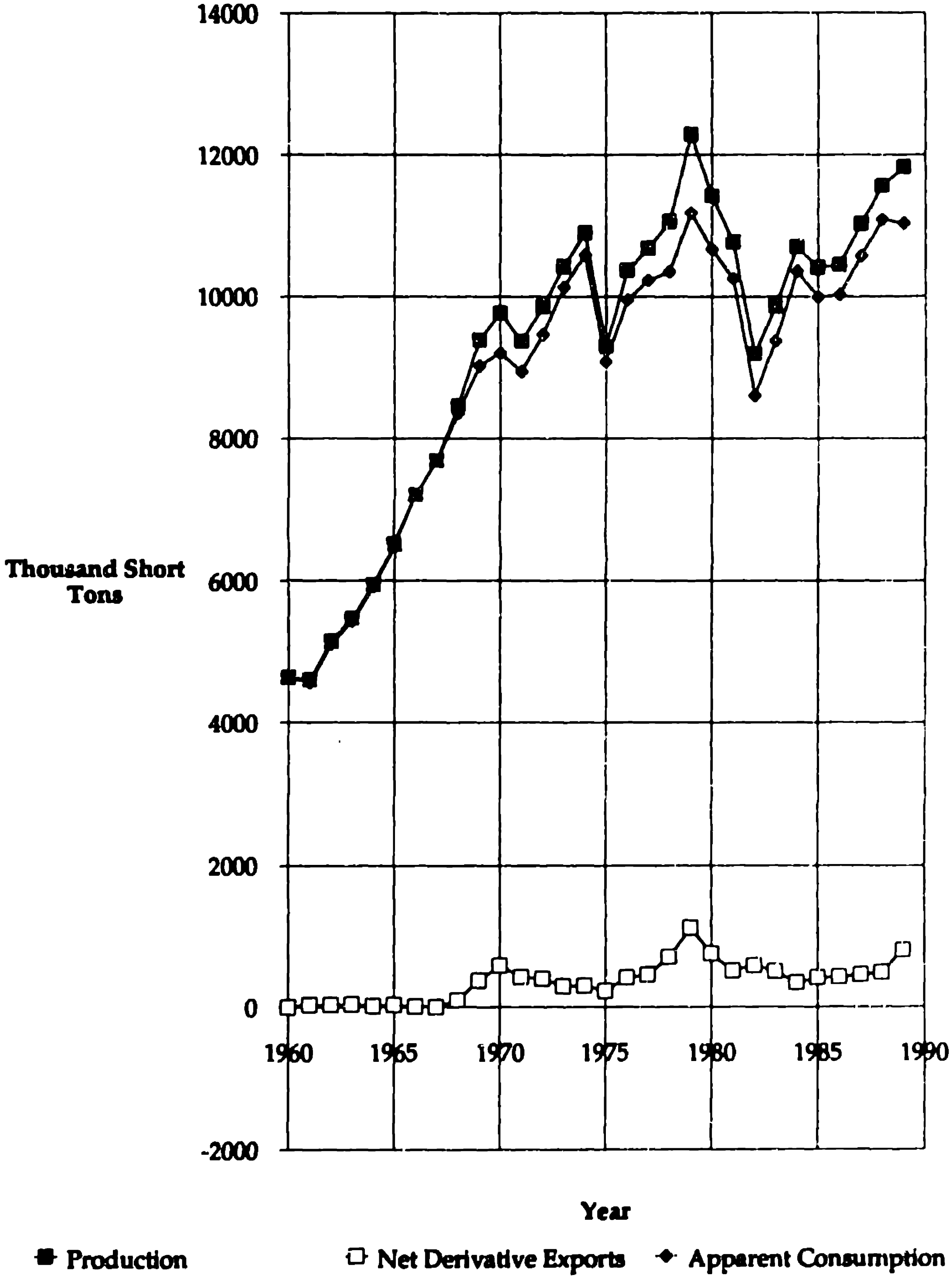
Domestic demand (Apparent Consumption) was calculated by subtracting net derivative exports from total production. Inventory change was not included because, for the most part, chlorine can not be inventoried because of its hazardous and reactive nature. In 1980, Dow used approximately 500 M-ST of chlorine to produce excess ethylene dichloride (EDC) as a means of storing

Table 4-1: Chlorine Supply and Demand

Year	Production M-ST	Net Derivative Exports	Apparent Consumption	Capacity M-ST	Utilization %	Chlorine Price $/ST	Real Chlorine Price 1982 $/ST
1960	4,637	0	4,637	5,095	91	59.24	170.23
1961	4,601	33	4,568	5,258	88	59.26	171.77
1962	5,143	34	5,109	5,364	96	58.04	171.21
1963	5,464	38	5,426	5,659	97	57.92	172.90
1964	5,945	20	5,925	5,987	99	55.94	166.49
1965	6,517	34	6,483	6,294	104	52.71	155.49
1966	7,204	4	7,200	6,913	104	51.73	152.15
1967	7,680	-3	7,683	7,744	99	51.20	149.71
1968	8,444	98	8,346	8,482	100	48.41	141.96
1969	9,376	372	9,004	9,170	102	47.49	138.86
1970	9,764	581	9,183	10,321	95	45.54	130.11
1971	9,352	422	8,930	10,633	88	45.42	127.58
1972	9,854	400	9,454	10,435	94	42.73	120.03
1973	10,420	290	10,130	10,820	96	46.73	124.28
1974	10,887	304	10,583	11,063	98	64.43	128.35
1975	9,287	225	9,062	12,414	75	94.10	151.77
1976	10,364	417	9,947	12,789	81	96.27	150.42
1977	10,676	453	10,223	13,074	82	98.92	150.11
1978	11,052	703	10,349	13,857	80	92.18	135.56
1979	12,291	1,117	11,174	14,295	86	94.70	124.61
1980	11,421	757	10,664	14,378	79	107.80	121.12
1981	10,763	515	10,248	14,418	75	94.66	96.20
1982	9,176	586	8,590	14,832	62	85.26	85.26
1983	9,86[illegible]	500	9,364	14,516	68	104.78	104.47
1984	10,700	343	10,357	14,070	76	137.59	133.71
1985	10,402	412	9,990	13,979	74	131.75	127.05
1986	10,442	422	10,020	13,267	79	119.78	116.74
1987	11,019	452	10,567	12,830	86	133.98	125.92
1988	11,568	490	11,078	11,712	99	115.00	98.88
1989	11,832	805	11,027	12,650	94	100.00	81.23

Sources:
Production, Capacity, and Price - The Chlorine Institute
Net Derivative Exports - Olin Corporation, Internal Report, 1990
Real Price - Chlorine Price Adjusted Using Chemical Industry Producer Price Index, from the Economic Report of the President to Congress, 1990
Apparent Consumption = Production - Net Derivative Exports

Figure 4-1: Chlorine Demand



chlorine.[11] They then consumed this EDC over the next two to three years to produce vinyl chloride monomer which is then used to produce polyvinyl chloride. This effectively increased the consumption in 1980 and reduced the consumption in the following few years.

Apparent consumption of chlorine has increased from 4,637 M-ST in 1960 to 11,027 M-ST in 1989 with an average annual growth rate of 3.0%. The growth rate per year has fluctuated quite widely throughout the period of study with years of significant decline as well as growth.

Imports and exports of elemental chlorine are relatively small because of the difficulties in transporting such a hazardous material. An analysis of chlorine trade, however, should include trade of compounds containing chlorine (chlorine derivatives). During the study period, net derivative exports of chlorine rose from essentially zero in 1960 to roughly 400 to 500 M-ST throughout most of the 1970s and 1980s with some variation around this average.

Table 4-2 gives a breakdown of the end users of chlorine. As shown, general organics comprise nearly 30% of the total consumption of chlorine. This market, however is somewhat fragmented by a variety of specialty chlorine derivative organics that are used in the industry. Included in this segment are chlorinated solvents that are raw materials to the production of chloro-fluorocarbons (CFCs). The EPA has instituted regulations to control and eventually eliminate the use of CFCs because they are suspected of damaging

[11]Patrick Baker, Manager Business Development, Olin Corporation, Personal Communication, 1991.

the ozone layer. Thus, growth in this industry is expected to slow due to these environmental pressures. These segments are, in general, highly dependent on chlorine as a raw material and are therefore very insensitive to price movements in the short term. Production in these industries will tend to fluctuate with the economy and GNP thereby leading chlorine demand to fluctuate with GNP.

Table 4-2: 1989 Chlorine End Use Profile

	Segment% Of Consumption
Organics	29.1
Vinyl Chloride/ Polyvinyl Chloride	28.6
Inorganics	10.6
Hydrochloric Acid	10.2
Paper Bleaching	15.0
Water Treatment	6.4
Total	100.0

Source: Olin Corporation, "Chlorine End-Use Analysis", Internal Report, 4/23/90

The next largest segment, vinyl chloride/polyvinyl chloride is very focused on the ultimate production of polyvinyl chloride. Polyvinyl chloride is essentially a commodity material and is used throughout the economy as a basic plastic material. This segment of the market would, therefore, tend to be linked closely with the general economy and GNP. In the short term, this market tends to be insensitive to changes in chlorine prices because chlorine is an essential raw material to the process. In the long term, however, changes in chlorine price will affect the competitiveness of PVC with other basic plastics.

Paper bleaching comprises the next largest segment of the market. Paper companies use chlorine in their pulping process to bleach the pulp white. Environmental concerns have recently arisen over toxic chemicals that may be discharged from this process and which are thought to be generated by the use of chlorine.[12] Because of this concern, paper manufacturers are switching to alternate bleaching technologies to reduce the formation of these toxic materials. The primary replacement technology involves the use of increased amounts of chlorine dioxide, and less chlorine in the primary bleaching stage. In the past, the primary bleaching stage would use only 10% chlorine dioxide. The new technology involves the use of 50% chlorine dioxide, thereby reducing the amount of chlorine needed.

The inorganics segment consists of a number of relatively small segments which are expected to grow slightly over the next few years without significant threat of substitution. These segments will tend to be insensitive to price movements because of the lack of substitution. Like other segments, however, this segment and its demand for chlorine will tend to be linked to the economy and GNP.

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[12] Marilynne Smart, Rice, G., Leder, A., Schlegel, W., Nakamura, E., "Chemical Economics Handbook Marketing Report - Chlorine/Sodium Hydroxide", Chemical Economics Handbook, SRI International, 1989, 733.1002 Q.

The hydrochloric acid segment represents an important portion of the consumption of chlorine. Hydrochloric acid (HCl) is produced as a by-product in many processes using chlorine. This by-product HCl must be either disposed of or sold. The economics of selling and disposing of this HCl will therefore impact the economics of the processes using chlorine. In addition, HCl consumption tends to be somewhat price sensitive because of its competition with other forms of acid such as sulfuric acid. Thus, this segment, and its demand for chlorine, will tend to be price sensitive.

The water treatment sector, however small, comprises a relatively stable sector of the market. Although this market is considered to be saturated, there are currently no substitutes threatening to displace chlorine from this market. This, however, may change in the near future as further environmental concern mounts over the use of chlorine.

Overall, the demand for chlorine tends to face few substitutes and should therefore be relatively price inelastic in the short run. On the other hand, the processes that use chlorine tend to move with the economy and GNP. Chlorine demand, therefore, should also fluctuate with GNP.

4.2 Caustic Soda Supply and Demand

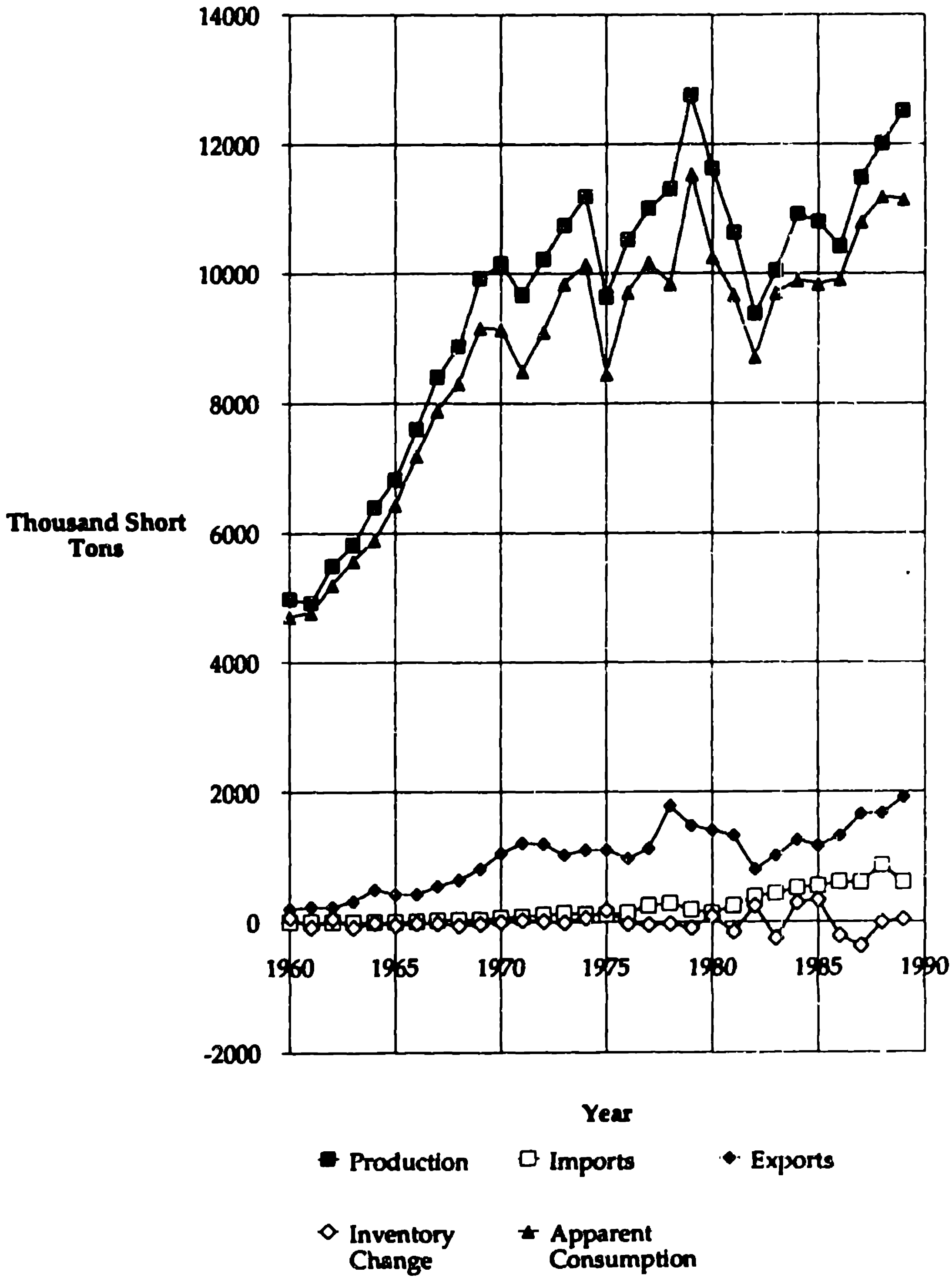
The components of caustic soda supply and demand are listed in Table 4-3 and plotted in Figure 4-2. Production of caustic soda has followed that of chlorine because of the co-production nature of the industry. The ratio of caustic soda production to chlorine production has declined through the 1960s to the early 1980s due to the increased production of chlorine through alternate technologies. This ratio has rebounded slightly over the past few

Table 4-3: Caustic Soda Supply and Demand

Year	Production M-ST	Caustic Soda/Chlorine Production Ratio	Imports M-ST	Exports M-ST	Inventory Change M-ST	Apparent Consumption M-ST	Caustic Soda Price $/ST	Caustic Soda Price 1982 $/ST
1960	4,972	1.07	1	200	67	4,706	51.60	148.28
1961	4,914	1.07	1	228	-79	4,766	48.93	141.83
1962	5,486	1.07	1	230	51	5,206	48.41	142.80
1963	5,814	1.06	1	321	-84	5,578	45.07	134.54
1964	6,389	1.07	1	500	-4	5,894	46.70	138.99
1965	6,813	1.05	3	423	-41	6,434	45.01	132.77
1966	7,596	1.05	9	429	-22	7,197	44.93	132.15
1967	8,398	1.09	23	555	-21	7,887	42.66	124.74
1968	8,868	1.05	39	646	-49	8,310	37.34	109.50
1969	9,917	1.06	40	814	-27	9,170	33.85	98.98
1970	10,141	1.04	63	1,061	-2	9,145	34.52	98.63
1971	9,667	1.03	76	1,222	25	8,496	42.85	120.37
1972	10,216	1.04	105	1,202	10	9,109	50.65	142.28
1973	10,734	1.03	135	1,034	-10	9,845	51.89	138.01
1974	11,189	1.03	119	1,110	59	10,139	72.46	144.34
1975	9,635	1.04	108	1,109	180	8,454	118.94	191.84
1976	10,516	1.01	146	979	-31	9,714	122.37	191.20
1977	11,000	1.03	249	1,125	-48	10,172	114.11	173.16
1978	11,309	1.02	283	1,788	-31	9,835	109.56	161.12
1979	12,759	1.04	183	1,485	-91	11,548	101.20	133.16
1980	11,625	1.02	132	1,414	91	10,252	124.58	139.98
1981	10,621	0.99	246	1,331	-147	9,683	178.39	181.29
1982	9,385	1.02	395	810	250	8,720	188.70	188.70
1983	10,039	1.02	438	1,023	-250	9,704	143.63	143.20
1984	10,914	1.02	526	1,260	290	9,890	116.88	113.59
1985	10,790	1.04	554	1,171	335	9,838	114.07	110.00
1986	10,405	1.00	616	1,322	-215	9,914	95.63	93.21
1987	11,486	1.04	607	1,660	-365	10,798	96.61	90.80
1988	12,008	1.04	875	1,680	0	11,203	175.00	150.47
1989	12,506	1.06	609	1,916	40	11,159	200.00	162.47

Sources:
Production, Inventory Change, and Price - Current Industrial Reports, Series M28A, U.S. Department of Commerce, Bureau of the Census
Imports - U.S. Imports for Consumption, IM 146 and FT 135, U.S. Department of Commerce, Bureau of the Census
Exports - U.S. Exports, IEM 546 and FT 410, U.S. Department of Commerce, Bureau of the Census
Real Price - Caustic Soda Price Adjusted Using Chemical Industry Producer Price Index, from the Economic Report of the President to Congress, 1990
Apparent Consumption = Production + Imports - Exports - Inventory Change

Figure 4-2: Caustic Soda Demand



years due to the low price of chlorine which has made alternate chlorine technologies uneconomical.

Imports of caustic soda, although not exceedingly large, have grown from essentially zero in 1960 to approximately 600 M-ST in 1989. Exports have continuously exceeded imports and have also grown, reaching over 1900 M-ST in 1989.

Changes in inventory have not been recorded continuously throughout the period but were estimated to be small, ranging from -365 M-ST to 335 M-ST.

Finally, apparent consumption has grown from 4706 M-ST in 1960 to 11,159 M-ST in 1989 with an average annual growth rate of 3.0%.
Like chlorine, the annual growth rate of caustic soda apparent consumption has fluctuated quite widely throughout the period of study with years of significant decline as well as growth. In general, the fluctuations of caustic soda growth have followed those of chlorine growth.

Table 4-4 lists the breakdown of caustic soda consumption by segment. Over 70% of caustic soda consumption is accounted for by three segments, inorganic chemicals, organic chemicals, and pulp and paper manufacturing.

Table 4-4: 1987 Caustic Soda End Use Profile

	Segment% of Consumption
Chemicals	
Inorganic	23.1
Organic	21.9
Pulp and Paper	25.3
Oil and Gas Industry	4.1
Soap and Detergent	2.9
Water	2.9
Miscellaneous	15.8

Total	100.0

Source: Olin Ccrporation, "Caustic Soda End-Use Analysis", Internal Report, 3/88

Chemical manufacturing is the largest consumer segment for caustic soda, comprising 45% of the caustic soda market. In this segment its primary uses include:

- waste acid neutralization
- process pH control
- off-gas scrubbing
- catalysis
- extraction

In all of these applications, caustic soda is used primarily as a means of providing a source of high pH or alkalinity. This segment of use is subject to a variety of process improvements that could potentially reduce the amount of caustic soda needed. Thus, one would expect this segment to be somewhat more price elastic than other segments. In addition, production in the chemicals industry tends to be tied with the state of the economy and with

GNP. As a result, caustic soda demand in this segment should also fluctuate with GNP.

The pulp and paper market is the next largest segment of caustic soda consumers, accounting for 25.3% of the caustic soda supplied in the U.S. Caustic soda, in this industry, is used primarily for three purposes which include:[13]

1) to help break down wood into pulp in the Kraft pulping process;
2) to extract lignin from the pulp during the bleaching process; and
3) to produce sodium hypochlorite which is also used in the bleaching process.

Other minor uses of caustic soda include water treatment, ion exchange resin regeneration, equipment cleaning, and off-gas scrubbing.

Growth of caustic soda consumption, in this industry is closely tied to the growth of the demand for pulp which is estimated to be less than 1% over the next several years. Environmental pressures are reducing the amount of sodium hypochlorite that is used in the bleaching process which will thereby reduce demand of caustic soda.

Also, either caustic soda or soda ash can be used in the pulping process. Caustic soda has been the chemical of choice because it is easier to handle (in liquid form) and can be purchased or manufactured on-site in conjunction with the required chlorine. In addition, use of caustic soda, versus soda ash, puts less of a demand on the chemical recovery systems used at paper mills.

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[13]Ibid, 733.1002 S.

But, as the price of caustic soda rises, more paper mills may increase their use of soda ash at the expense of caustic soda. Thus, use of caustic soda in this industry should be price elastic but less so than that of other chemical segments. The paper industry, and its use of caustic soda, will also tend to fluctuate with the economy and GNP.

The remaining segments of caustic soda consumption are all small and tend to be driven by the state of the economy and should fluctuate with GNP. Growth in these areas is not expected to exceed 2% per year.

Overall, caustic soda has more substitutes than does chlorine. Caustic soda demand should therefore be more price elastic than chlorine demand. The users of caustic soda also tend to be tied to the economy and GNP which will cause caustic soda demand to fluctuate with GNP.

4.3 Soda Ash Supply and Demand

The components of soda ash supply and demand for the period 1960 to 1989 are listed in Table 4-5 and plotted in Figure 4-3. Production of soda ash has increased at an average annual rate of 2.2%, significantly less than that of chlorine and caustic soda.

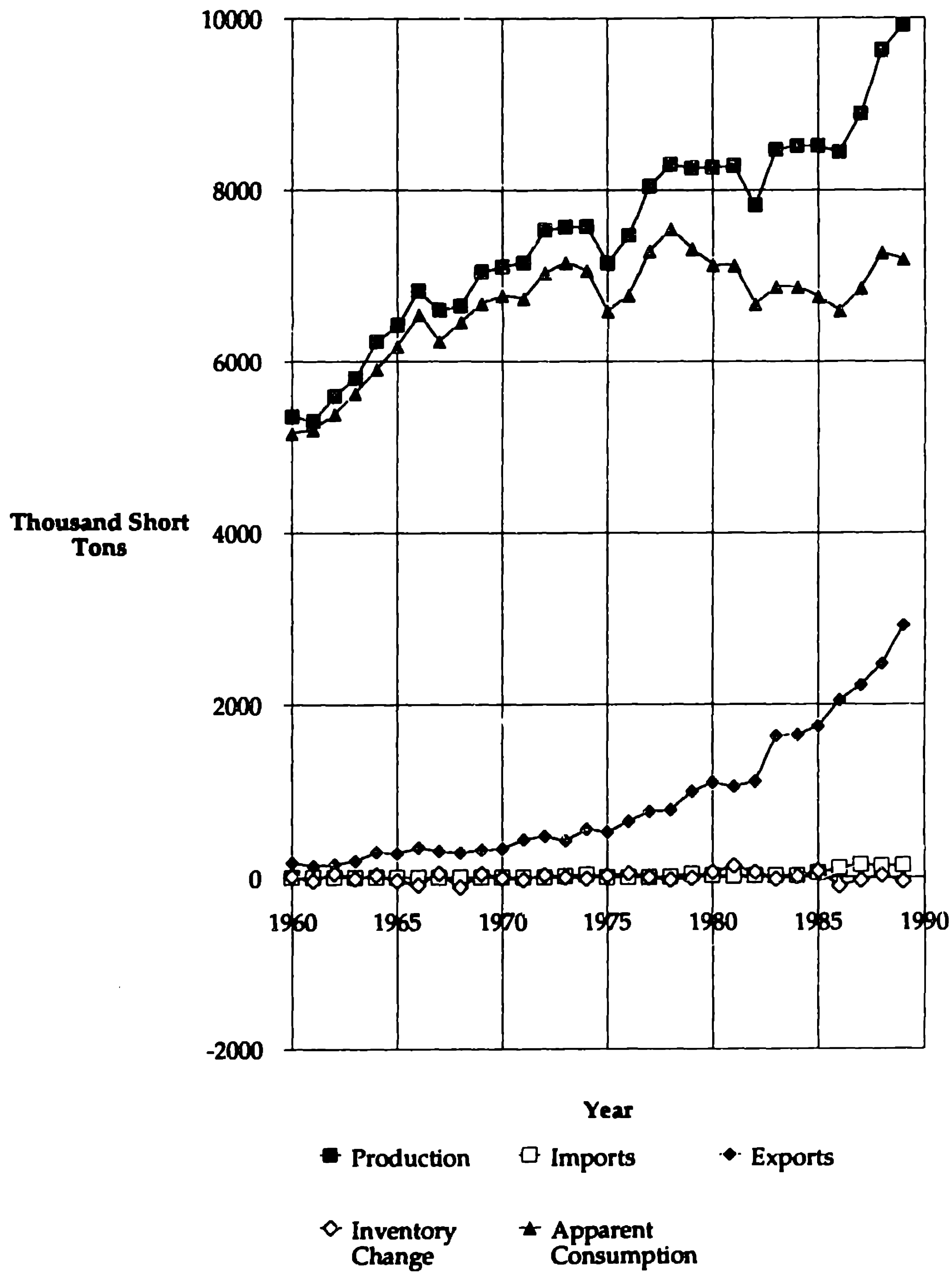
Imports of soda ash have been relatively small during the study period increasing from zero in 1960 to 142 M-ST in 1989. Exports, on the other hand, have accounted for a significant portion of production. Exports have increased from 170 M-ST in 1960 to 2919 M-ST in 1989, growing at an average annual rate of 10.3%. This large increase has been due to the lower costs of

Table 4-5: Soda Ash Supply and Demand

Year	Production M-ST	Imports M-ST	Exports M-ST	Inventory Change M-ST	Apparent Consumption M-ST	Capacity M-ST	Utilization %	Soda Ash Price $/ST	Real Soda Ash Price 1982 $/ST
1960	5,348	0	170	15	5,163	6,490	82	25.79	74.11
1961	5,301	0	132	-36	5,205	6,465	82	25.36	73.51
1962	5,585	0	152	46	5,387	6,950	80	24.88	73.39
1963	5,801	0	193	-14	5,622	6,890	84	24.68	73.67
1964	6,223	0	291	26	5,906	7,011	89	23.88	71.07
1965	6,420	0	277	-36	6,179	7,061	91	23.24	68.55
1966	6,809	0	346	-85	6,548	7,190	95	23.40	68.82
1967	6,591	0	304	49	6,238	7,070	93	23.19	67.81
1968	6,638	0	288	-112	6,462	7,126	93	20.61	60.44
1969	7,035	0	324	41	6,670	7,800	90	20.41	59.68
1970	7,093	0	336	-8	6,765	7,920	90	21.03	60.09
1971	7,139	0	437	-29	6,731	7,520	95	21.21	59.58
1972	7,527	1	480	24	7,024	8,700	87	22.28	62.58
1973	7,560	10	425	-1	7,146	8,100	93	25.36	67.45
1974	7,566	32	564	-16	7,050	8,100	93	33.87	67.47
1975	7,130	2	529	18	6,585	8,580	83	42.20	68.06
1976	7,459	0	645	48	6,766	9,580	78	49.70	77.66
1977	8,038	1	759	-1	7,281	9,580	84	54.19	82.23
1978	8,290	8	779	-25	7,544	9,620	86	54.51	80.16
1979	8,253	40	997	-8	7,304	8,820	94	64.55	84.93
1980	8,257	18	1,094	64	7,117	9,620	86	89.85	100.96
1981	8,281	12	1,050	131	7,112	10,360	80	91.19	92.67
1982	7,819	18	1,109	61	6,667	11,160	70	88.35	88.35
1983	8,467	20	1,636	-18	6,869	11,160	76	76.95	76.72
1984	8,511	17	1,648	16	6,864	11,160	76	67.00	65.11
1985	8,511	56	1,747	70	6,750	11,160	76	67.82	65.40
1986	8,438	106	2,049	-98	6,593	10,560	80	65.29	63.64
1987	8,891	150	2,224	-35	6,852	10,485	85	66.78	62.76
1988	9,632	132	2,467	29	7,268	10,485	92	66.96	57.58
1989	9,915	142	2,919	-45	7,183	10,560	94	77.07	62.61

Sources:
Production, Inventory Change, Capacity and Price - Current Industrial Reports, Series M28A, U.S. Department of Commerce, Bureau of the Census
Exports - U.S. Export, FT 410, FT 135, EM 546, U.S. Department of Commerce, Bureau of the Census
Imports - U.S. Imports for Consumption, IM 146, U.S. Department of Commerce, Bureau of the Census
Real Price - Soda Ash Price Adjusted Using Chemical Industry Producer Price Index, from the Economic Report of the President to Congress, 1990
Apparent Consumption = Production + Imports - Exports - Inventory Change

Figure 4-3: Soda Ash Demand



production that U.S. manufacturers have enjoyed over the past 20 years through the availability of natural production.

Apparent consumption of soda ash has increased from 5,163 M-ST in 1960 to 7,183 M-ST in 1989, with an average annual growth rate of only 1.2%. The difference between the growth in production and the growth in domestic consumption is due to the large increase in exports. Annual changes in consumption have fluctuated somewhat, in a similar fashion to that of both chlorine and caustic soda.

Table 4-6 gives the breakdown of soda ash consumption by major segment.

Table 4-6: 1989 Soda Ash End Use Profile

Segment	% of Consumption
Glass	50.9
Chemicals	21.8
Soaps and Detergents	12.1
Pulp and Paper	1.8
Water Treatment	1.4
Flue Gas Desulfurization	3.2
Other	8.8
Total	100.0

Source: Kostick, D.S., "Soda Ash Minerals Yearbook", U.S. Department of the Interior, Bureau of Mines, 1989

By far, the largest consumer of soda ash is the glass industry, accounting for 50.9% of domestic consumption in 1989. Soda ash, in this industry, is used as a source of alkali (Na_2O) in the glass formulation which reduces the temperature necessary to form glass.[14] Typically, glass formulations will contain about 12-15% alkali by weight. This corresponds to approximately 20-25% of soda ash by weight. The use of soda ash in this segment has been declining somewhat due to the increased recycle of used glass and increased competition of plastic and aseptic containers.

In general, however, this industry relies exclusively on soda ash as its alkali source and would tend to be relatively price inelastic. Also, glass production tends to fluctuate with the economy and GNP. Soda ash consumption in this segment will, therefore, also fluctuate with GNP.

The chemical industry accounts for 21.8% of total domestic soda ash consumption. Soda ash in this industry is used as a general source of alkali and competes most heavily with caustic soda. Of the chemicals it serves, soda ash is used primarily as a relatively less expensive source of sodium. Caustic soda, on the other hand, is used both as a source of sodium and as a source of high pH. Caustic soda and soda ash will compete in this market based on the technology of the particular chemical production and on the price differential between caustic soda and soda ash. This segment will, therefore, tend to

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[14]F. Alan Ferguson, Callison, S.L., Shimosato, J., and Garnett, A., "Chemical Economics Handbook Product Review - Sodium Carbonate and Sodium Bicarbonate", Chemical Economics Handbook, SRI International, 1984, 733.2000 W

demonstrate some price elasticity. Use of soda ash in this segment will also fluctuate with GNP because of the cyclical nature of the chemical industry.

The next largest segment is soaps and detergents, accounting for 12.1% of domestic soda ash consumption in 1989. Use of soda ash in this industry varies by the particular product and can range from less than 1% to 70% by weight.[15] Caustic soda and soda ash compete rather heavily in this market as many of these operations can use either as a source of alkali. Growth in this segment is expected to be similar to the growth in GNP. Again, soda ash consumption in this segment will be price elastic and will move in relation to GNP.

The remainder of soda ash consumer segments are all relatively small. Of them, only flue gas desulfurization is expected to have any significant growth, which will be spurred by new environmental regulation to control flue gas emissions.

Overall, soda ash consumption will tend to be price elastic, but more importantly, will fluctuate with the price of caustic soda. Like caustic soda, changes in soda ash consumption will also follow changes in GNP.

4.4 Alkali Equivalent Demand

Using these conversion factors, the apparent consumptions of caustic soda and soda ash were converted to alkali equivalent consumptions. These are

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[15]Ibid, 733.2001 E

plotted in Figure 4-4. Figure 4-5 plots the soda ash fraction of total alkali consumption over time.

Total alkali consumption grew steadily throughout the 1960s, increasing from 6,571 M-ST in 1960 to 10,874 M-ST in 1970. Total alkali consumption growth has fluctuated widely since 1970. By 1989, total consumption reached 12,647 M-ST. The soda ash portion of total alkali consumption fell steadily from 46% in 1960 to 33% in 1989.

Total alkali consumption should fluctuate with the price of caustic soda because both caustic soda and soda ash consumption will tend to move with this price. Also, total alkali consumption should be related to GNP, reflecting the cyclical nature of both caustic soda and soda ash.

Figure 4-4: Alkali Consumption

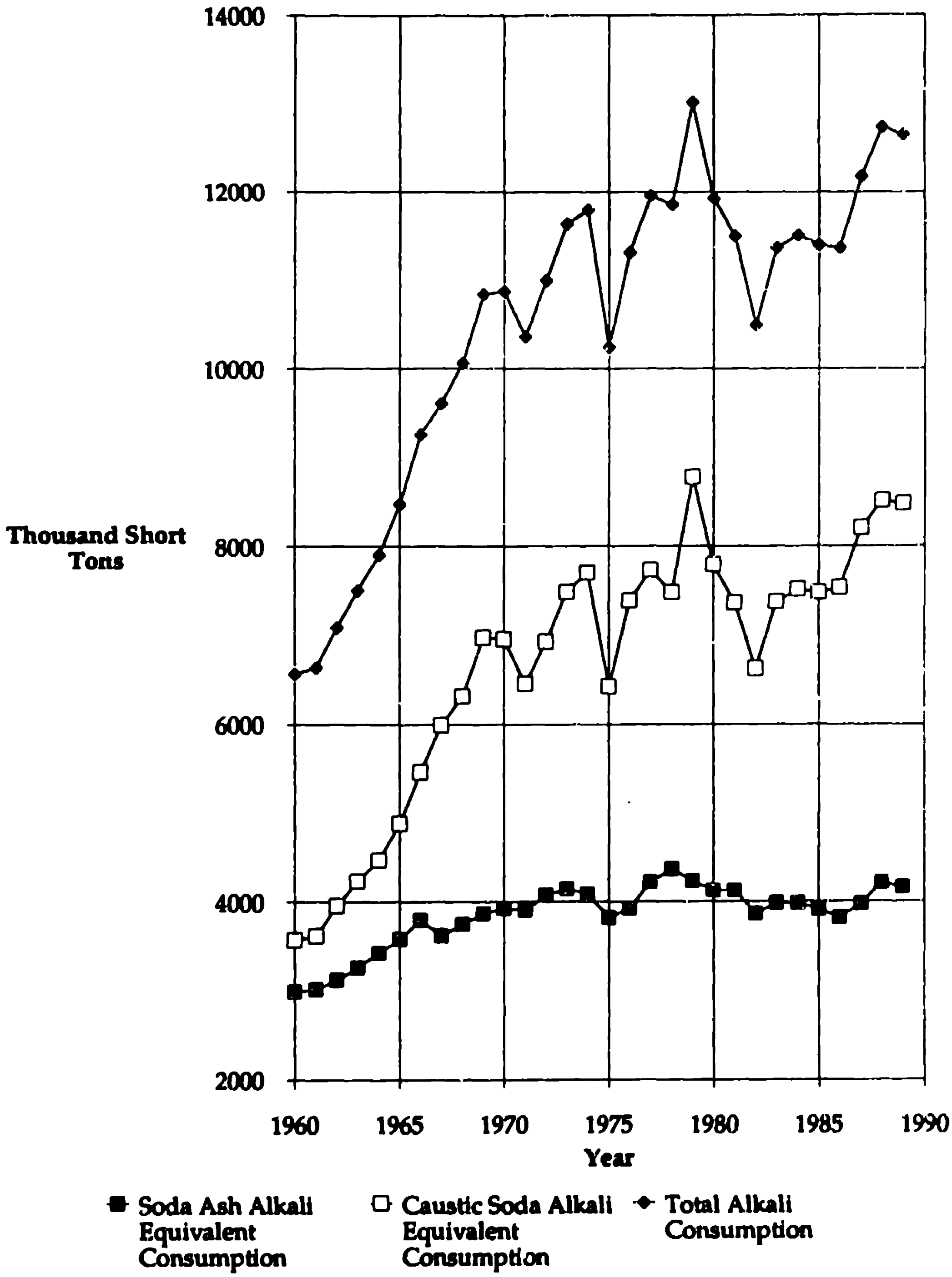
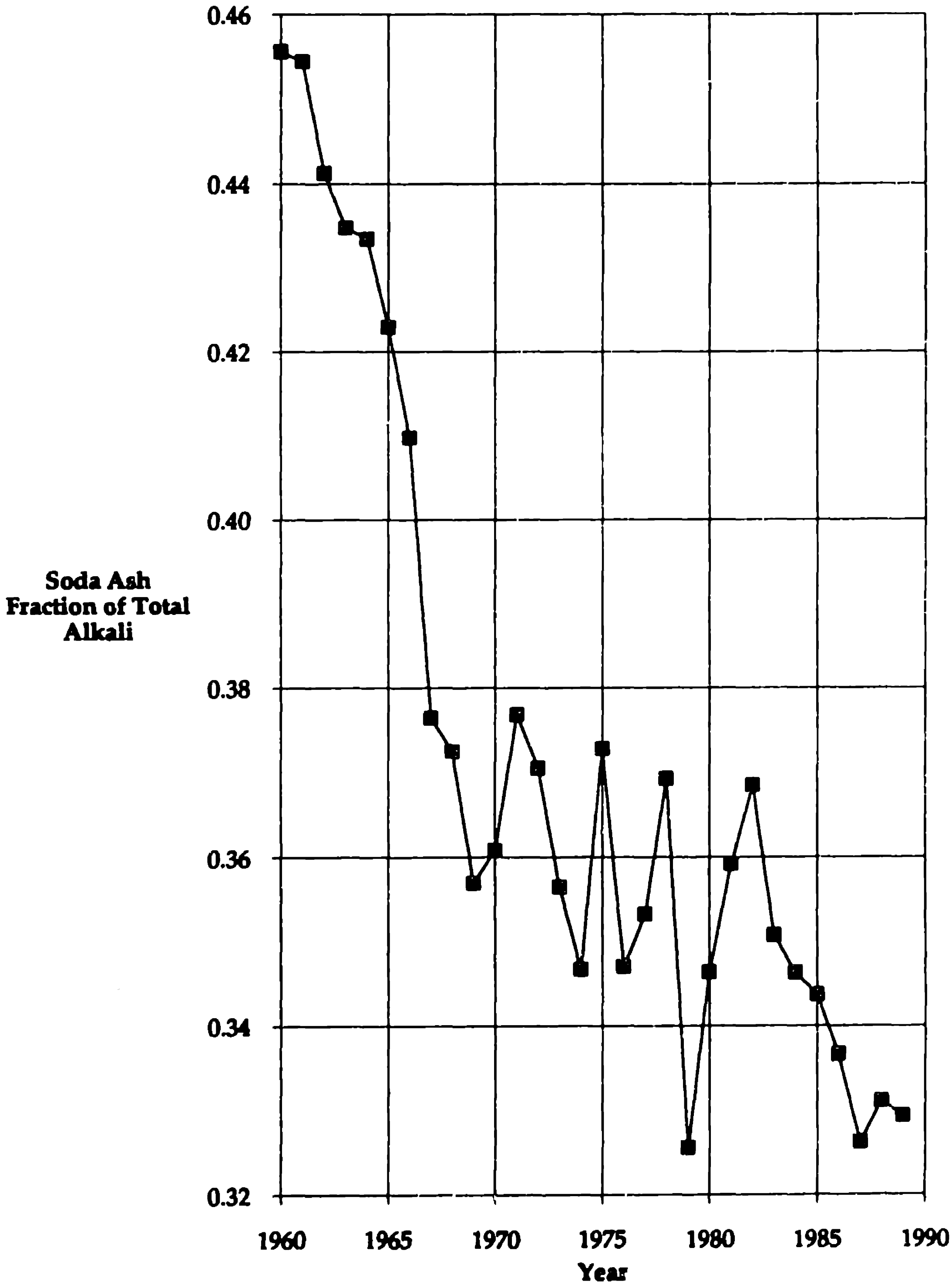


Figure 4-5: Soda Ash Fraction of Total Alkali



CHAPTER 5

PRICE TRENDS

Data for prices was collected for chlorine, caustic soda, and soda ash. This data represents the industry annual average prices for these materials. Prices for different producers and within different times of the year may vary slightly. These variations, however, do not significantly affect the accuracy of the price data. Overall, price data should be accurate to within 2%.

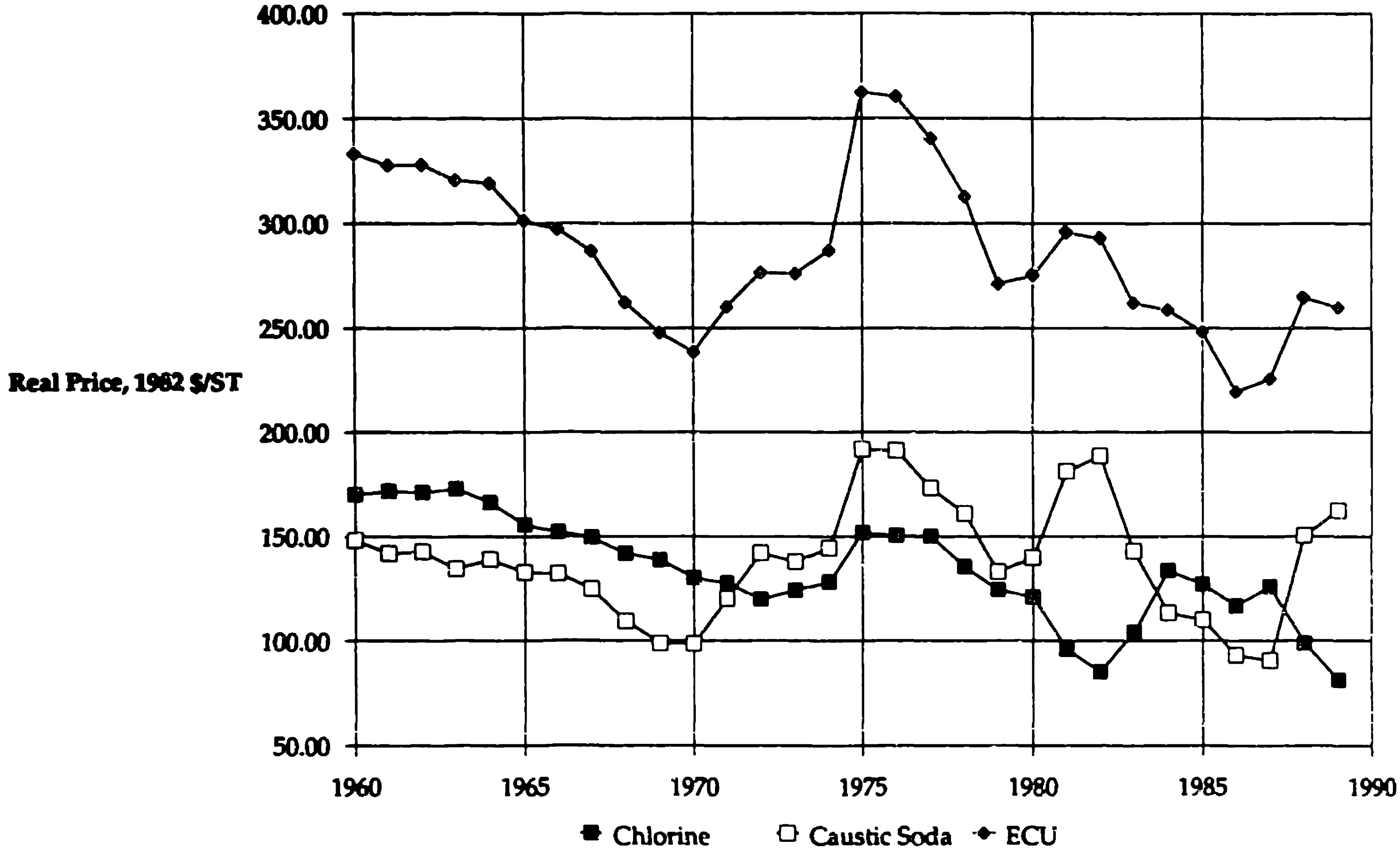
5.1 Chlorine, Caustic Soda and ECU Price Trends

The historical prices of chlorine and caustic soda are plotted in Figure 5-1. In addition, Figure 5-1 includes an ECU price which is calculated based on the price of 1 ton of chlorine plus 1.1 tons of caustic soda. The prices of chlorine and caustic soda have varied substantially over the thirty year period. At times, the chlorine price exceeded that of caustic soda and at other times, the caustic soda price exceeded that of chlorine.

This price fluctuation depended on the relative supply and demand of the two chemicals at the time. Because of the co-production nature of the business, the two chemicals have to be priced such that both will sell in proportional amounts. For example, if the demand for chlorine were low while that of caustic soda was not, then chlorine would have to be priced low in order to sell it. At the same time, the price of caustic soda would have to rise to dampen the caustic demand and to provide a profit on the combined ECU production.

Based on this price interaction between caustic soda and chlorine, one would expect the price of an ECU to be much more stable than that of either chlorine

Figure 5-1: Real Prices of Chlorine, Caustic Soda, and ECU



or caustic soda. As can be seen in Figure 5-1, this is indeed the case. Although the price of an ECU has varied, it has shown somewhat more stability than that of chlorine and caustic soda.

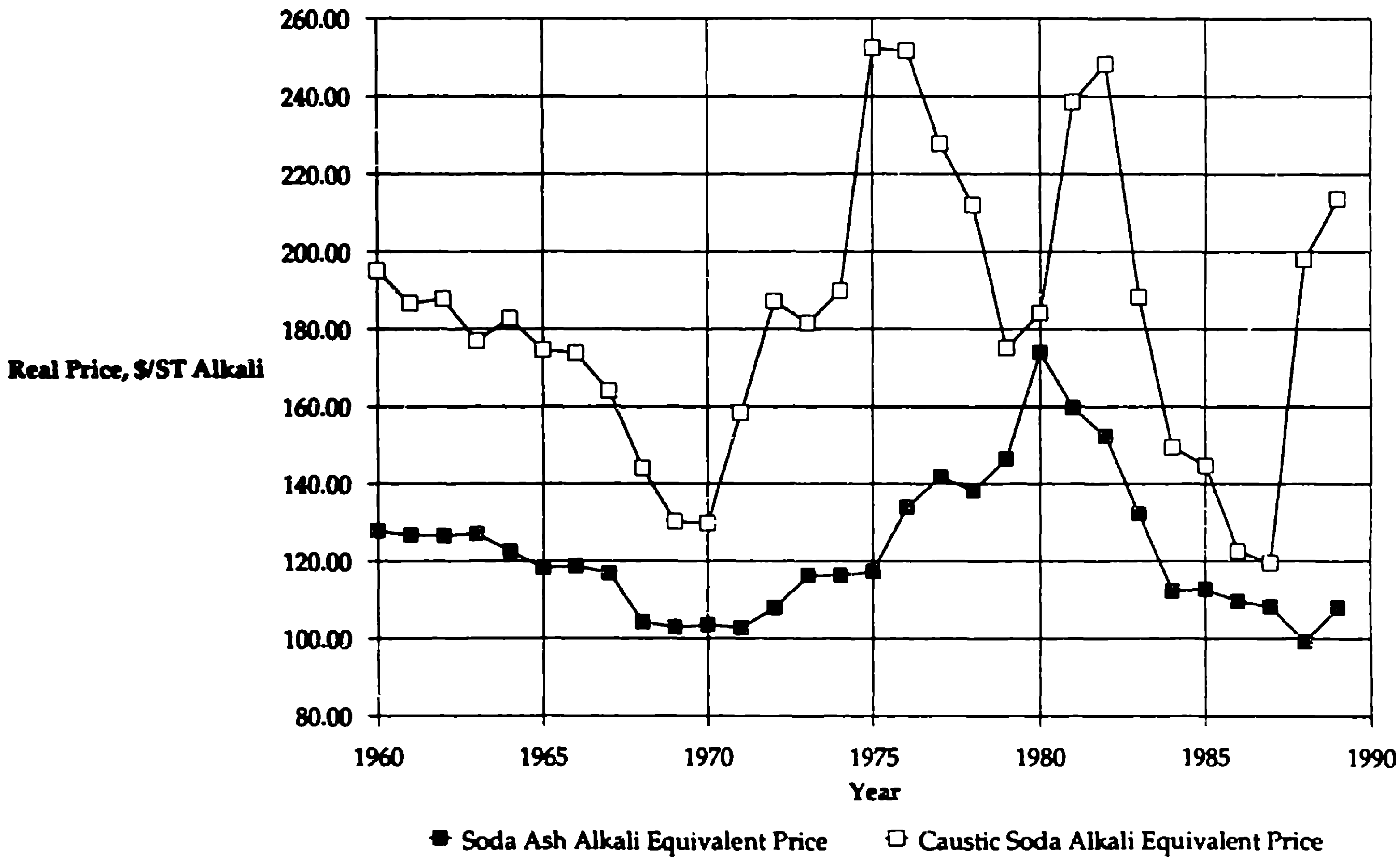
5.2 Soda Ash and Caustic Soda Price Trends

The relative alkali equivalent prices of caustic soda and soda ash were calculated using the alkali equivalent conversion factors given in Section 5.3 and are plotted in Figure 5-2. It should be noted that these prices do not include freight cost which can be a significant portion of the price paid by the consumer. These data therefore reflect the prices received by the producers of caustic soda and soda ash. Consumers of caustic soda are generally located closer to caustic soda producers. Soda ash, however, is produced primarily in Wyoming and must, on average, be shipped greater distances to the consumer. Thus, the shipping costs of soda ash tend to be higher than those of caustic soda.

Figure 5-2 shows that the alkali equivalent price of caustic soda has indeed exceeded that of soda ash over the past thirty years. This might be expected because of the costs of converting soda ash into caustic soda, the fact that caustic soda is available as a liquid which is easier to handle and, finally, the lower shipping costs of caustic soda.

It also appears that the alkali equivalent price of soda ash has moved with some lag in relation to the alkali equivalent price of caustic soda. Again, because soda ash can be substituted for caustic soda, one would expect the supply/demand balances for caustic soda and soda ash to be linked. In particular, a high price of caustic soda would lead marginal users to switch to

Figure 5-2: Alkali Equivalent Real Prices of Soda Ash and Caustic Soda



soda ash and thereby increase the demand for soda ash. This rise in soda ash demand would then lead soda ash producers to raise their price.

In April of 1989, soda ash producers responded in just this way. General Chemical Corp. and Tenneco Minerals Co. announced a rise in their price of soda ash due to the high demand. This strong demand was caused by the substitution of the less expensive soda ash for the higher priced caustic soda.[16] This, in turn, resulted in soda ash supply shortage which led soda ash suppliers to renegotiate their contracts.

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16 Dennis S. Kostick, "Soda Ash", US. Department of the Interior, Bureau of Mines, 1989.

CHAPTER 6

MODELING METHODOLOGY

The purpose of this study was to provide a mathematical explanation of how prices and consumption vary in the chlorine and alkali markets. As previously explained, the co-production nature of chlorine and caustic soda strongly affects how these chemicals are priced and how their consumption varies with price. In addition, soda ash is the prime substitute for caustic soda in the alkali market and its pricing and consumption patterns should be strongly correlated to those of caustic soda. Thus, these three commodities interact in such a way that makes pricing and consumption analyses quite complex.

In this study, two basic models are examined which include:

- An elasticity model that examines income and price elasticities of chlorine, total alkali, and soda ash.

- A time series model that examines the trend of consumption and prices as a function of time only.

6.1 Elasticity Model

The elasticity model assumes that consumptions of chlorine, caustic soda, and soda ash vary as some function of income (GNP), prices, and their lags. Real variables (versus nominal) were used because these can be compared across years.

In addition, caustic soda and soda ash consumption were modeled together as total alkali. As explained in section 5.3, caustic soda and soda ash are used, primarily, as sources of alkali. Thus, the best description of the demand in this industry examines the demand for total alkali. Finally, the demand for soda ash was examined separately so that its net effect on alkali demand could be separated from that of caustic soda. The price of caustic soda was used to describe demand in the analysis of total alkali. The prices of soda ash and caustic soda have historically been closely related because of the strong competition between the chemicals as sources of alkali.

Thus, the overall model would look something like:

$$C^{Cl}_{t} = F(GNP_{t}; P^{Cl}_{t}; \text{lags of } P^{Cl})$$

$$C^{Alk}_{t} = F(GNP_{t}; P^{CS}_{t}; \text{lags of } P^{CS})$$

$$C^{SA}_{t} = F(GNP_{t}; P^{CS}_{t}; \text{lags of } P^{CS})$$

$$C^{CS}_{t} = C^{Alk}_{t} - C^{SA}_{t}$$

$$P^{SA}_{t} = F(P^{CS}_{t}; \text{lags of } P^{CS})$$

Where:

C^{Cl}_t = Chlorine consumption in year t

C^{Alk}_t = Alkali consumption in year t

C^{CS}_t = Caustic soda consumption in year t

C^{SA}_t = Soda ash consumption in year t

P^{Cl}_t = Average annual real chlorine price in year t

P^{CS}_t = Average annual real caustic soda price in year t

GNP_t = Real GNP in year t

The natural logarithms of all variables were used as inputs to the regression analysis. Coefficients from this type of regression give elasticities directly and are thus more easily interpretable. It also assumes that elasticities are uniform and do not vary with price.

Two types of models were used for the elasticity analysis which included:

- **Straight Regression** - Regressing logged consumption as a function of logged GNP and logged prices.

- **Differenced Regressions** - Regressing annual *changes* in logged consumption versus annual *changes* in logged GNP and annual *changes* in logged prices.

The straight regressions assume that consumption in any given period will be a function of the level of GNP and of prices. The differenced regressions assume that consumption will *change* in response to *changes* in GNP and prices.

The results of the straight regression model are discussed in Appendix A. This model gave several results that were difficult to explain and also showed that differences in variable might be important to consider. Because of this, the differenced models were selected as a better picture of the variations in consumption as a function of income and prices. The differenced equations that best describe consumption behavior for chlorine, caustic soda, and soda ash are summarized and discussed in Section 7.1

6.2 Time Series Model

The time series model assumes that the demands and prices for chlorine, caustic soda, and soda ash follow some time cycle that can be predicted as a function of time without other predictor variables.

One explanation for these cycles is as follows:

> A low price will lead to a high demand which, in turn, will lead to a high price. The high price will then lead to a reduction in demand. Finally, the reduced demand will create an over-capacity in the industry and producers will lower their prices to start the cycle all over again. The times series model assumes that this pattern occurs with some regular frequency over a certain number of years.

Thus, the time series model that describes this industry will look something like:

$$C^{Cl}_t = F(C^{Cl}_{t-1}; \text{cycle factor}_t)$$

$$C^{Alk}_t = F(C^{Alk}_{t-1}; \text{cycle factor}_t)$$

$$C^{SA}_t = F(C^{SA}_{t-1}; \text{cycle factor}_t)$$

$$C^{CS}_t = C^{Alk}_t - C^{SA}_t$$

$$P^{Cl}_t = F(P^{Cl}_{t-1}; \text{cycle factor}_t)$$

$$P^{CS}_t = F(P^{CS}_{t-1}; \text{cycle factor}_t)$$

$$P^{SA}_t = F(P^{CS}_t; \text{lags of } P^{CS})$$

where: cycle factor is some factor that ranges from +1 to -1 over the period of time that the variable cycles through. In particular, the cycle factor will be a cosine function as follows:

$$\text{cycle factor}_t = \text{Cosine}(\pi/N^*(\text{Year}_t - \text{Reference Year}))$$

$\pi = 3.14159$

N = Number of years in the cycle

Year_t = Year of period t

Reference Year = Year at which the cycle starts.

This cycle factor will therefore give an estimate of when growth in the industry can be expected to increase or decrease. The function predicts that the log of price or consumption will be higher than the general trend when the cycle factor is positive and lower than the general trend when the factor is negative.

6.3 Initial Data Set Analysis

As described in section 6.1, this model compares changes in consumption versus changes in real GNP, real price, and its lags. Figure 6-1 plots chlorine, total alkali, and soda ash consumptions versus GNP. Figure 6-2 plots of chlorine consumption versus real chlorine price. Figures 6-3 and 6-4 plot the consumptions of total alkali and soda ash versus the real price of caustic soda.

Chlorine, total alkali, and soda ash consumptions show clear correlations with GNP throughout the thirty year study period. The relationships with price, however, appear somewhat different. The trends in the data of the first fifteen years of the study period, appear to be different from those of the following fifteen years. In general, the demand for all three chemicals consistently grew during 1960 to 1974. After that period, these industries matured and consumption was driven more by the supply/demand balance.

In the early 1970s, environmental issues became much more of a concern in the U.S. Some of these concerns have been targeted at chlorine and its derivative products and have resulted in a reduction in the demand for these products. In addition, the oil shock in 1974 put pressure on the suppliers of chlorine and caustic soda because of their high dependence on power. Thus, these two events created pressures that changed the nature of the demand for chlorine, caustic soda, and soda ash.

Because of these differences, the data set was divided into two 15-year subsets; 1960 to 1974, and 1975 to 1989. This division provides an analysis of how elasticities and general trends changed as these industries matured.

Figure 6-1: Chlorine, Total Alkali, and Soda Ash Consumptions versus GNP

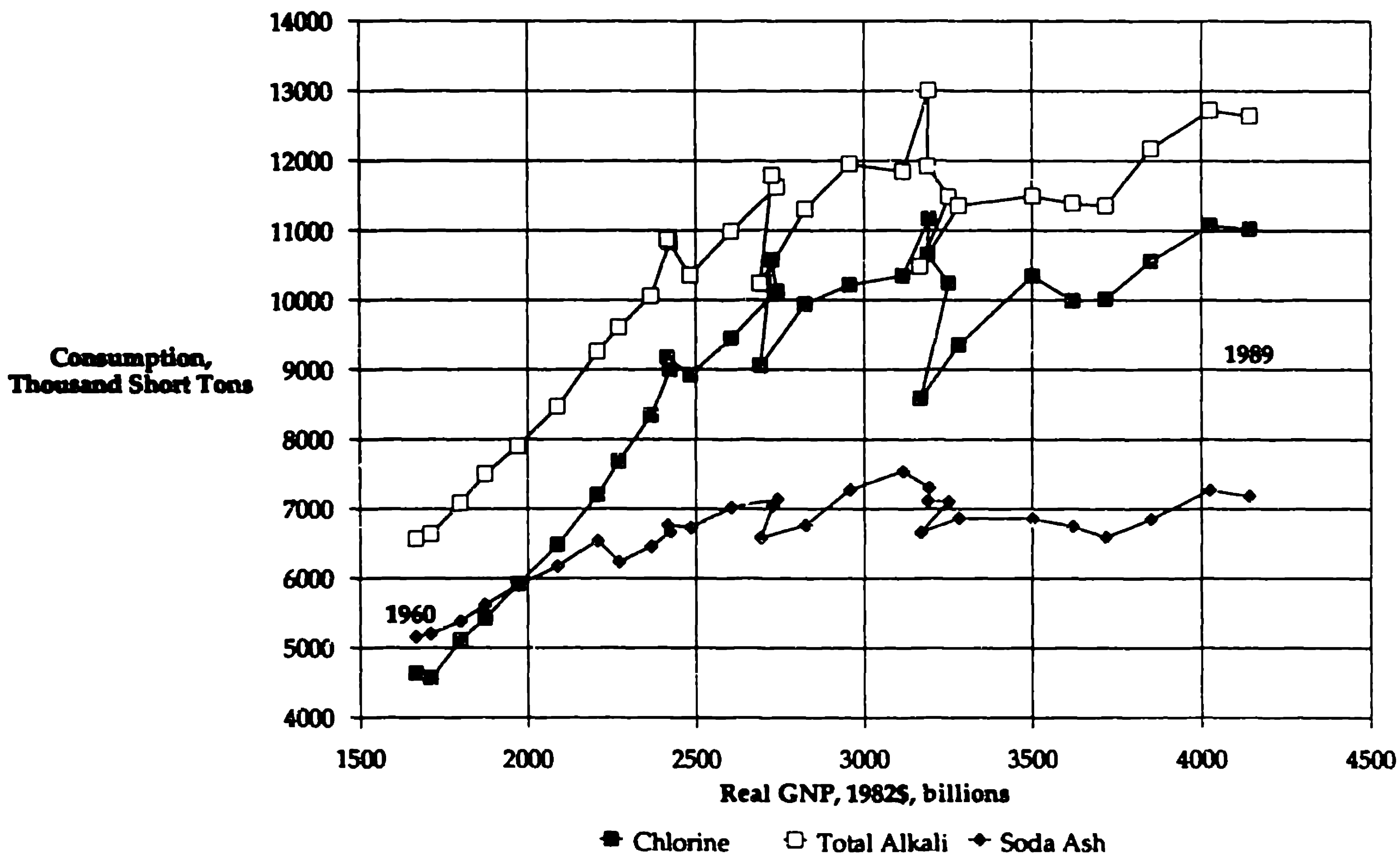


Figure 6-2: Chlorine Consumption versus Real Chlorine Price

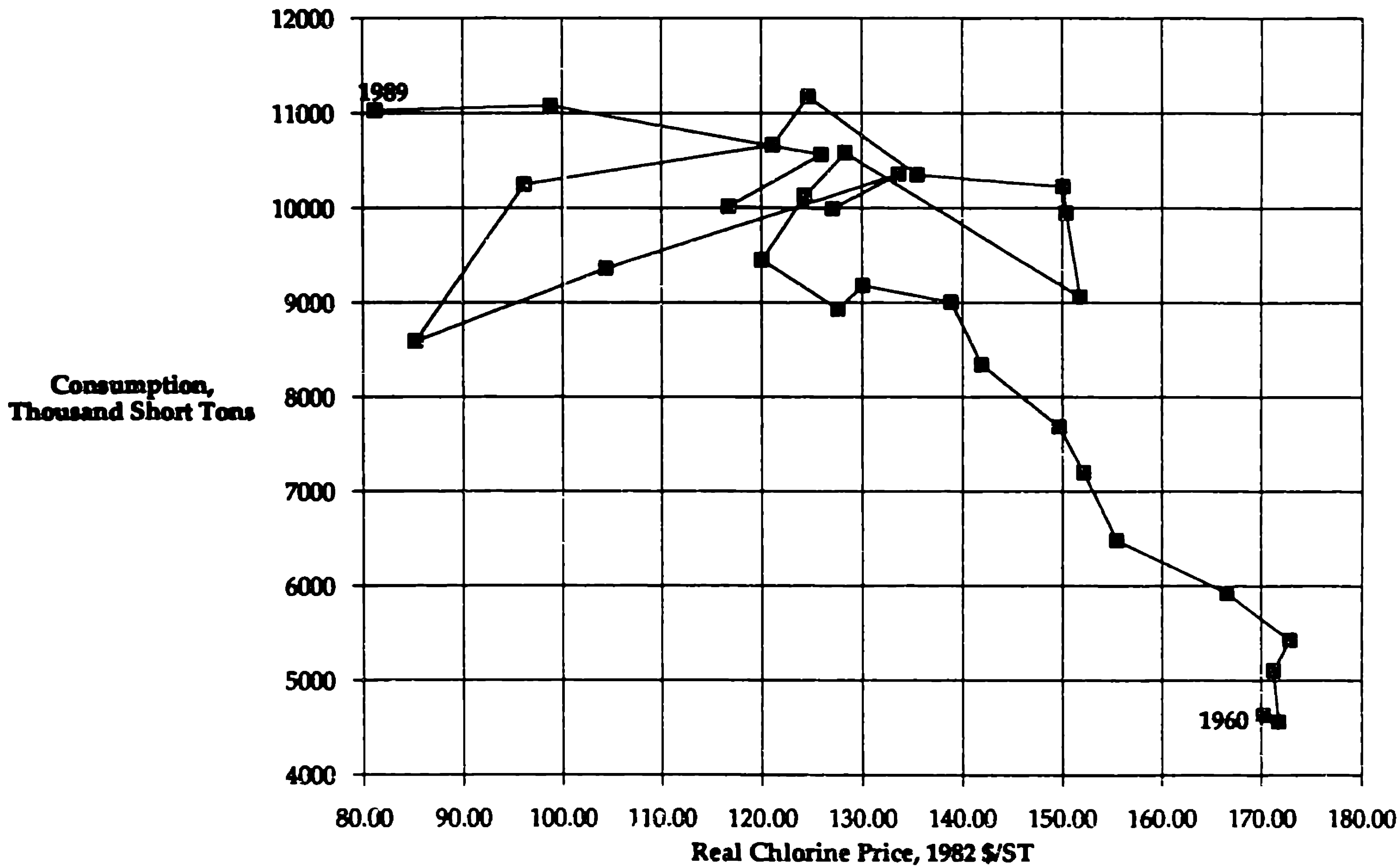


Figure 6-3: Total Alkali Consumption versus Real Caustic Soda Price

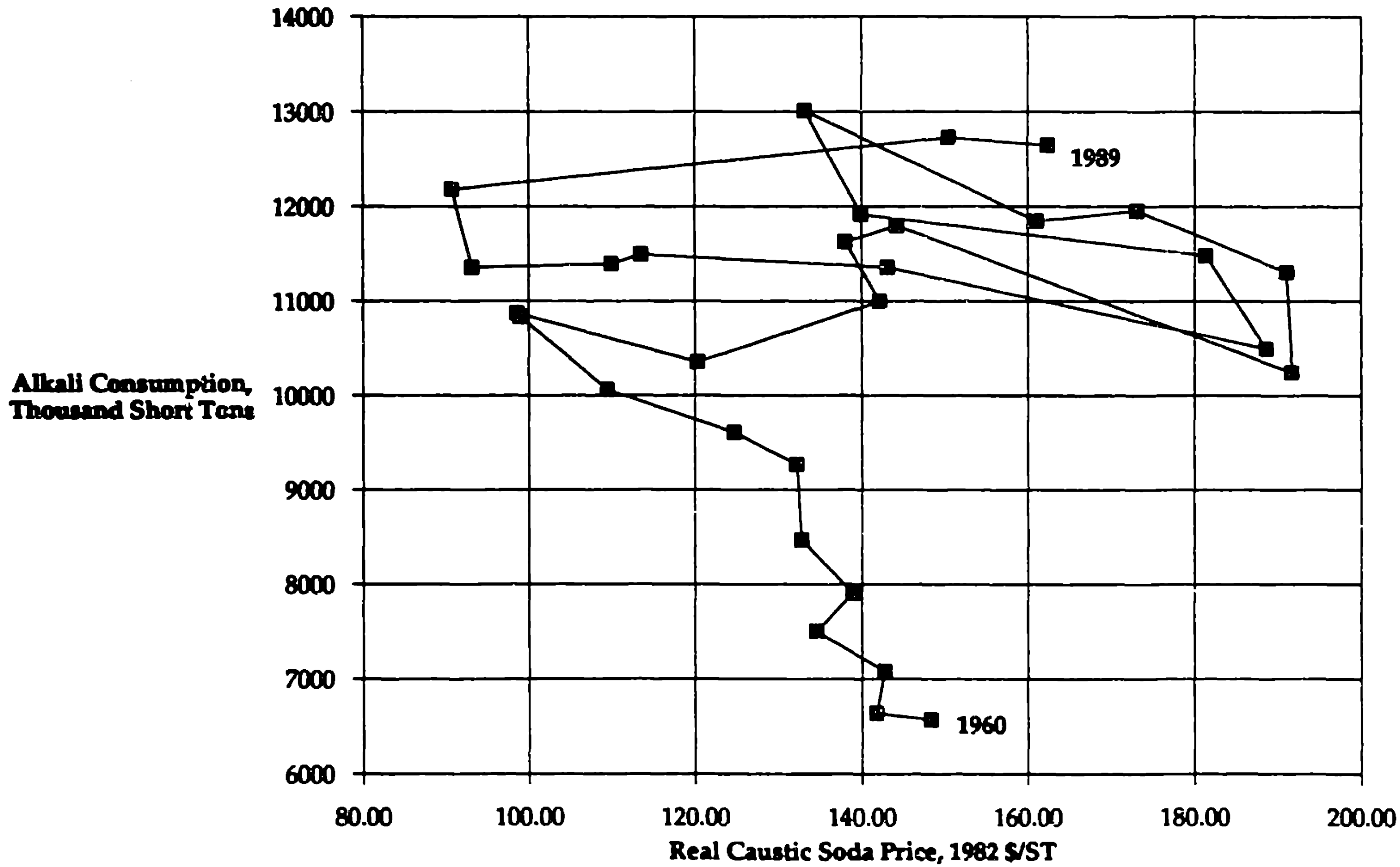
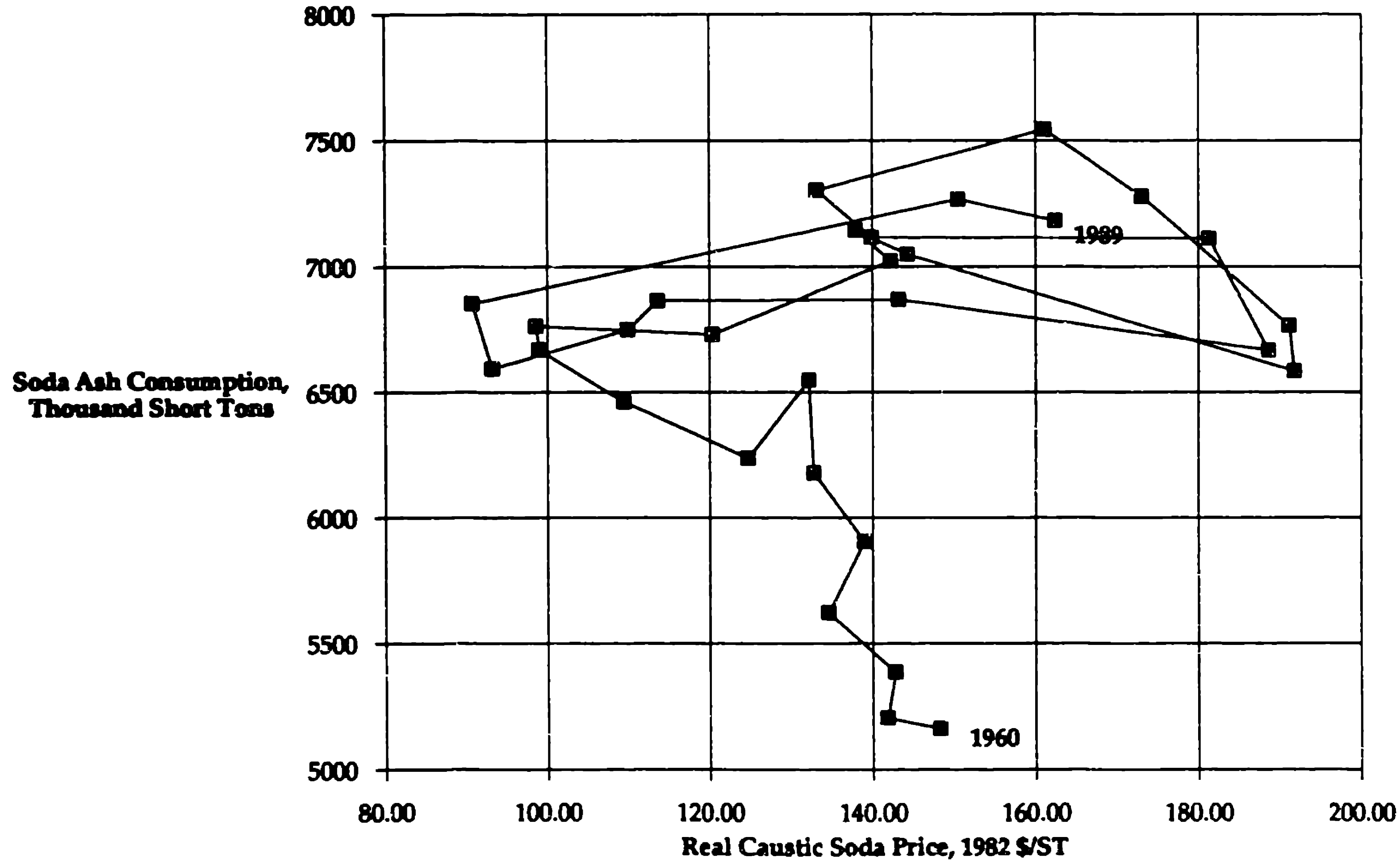


Figure 6-4: Soda Ash Consumption versus Real Caustic Soda Price



CHAPTER 7

REGRESSION RESULTS

7.1 Differenced Logarithmic Regression Analysis

Stepwise regression was used to determine the most significant variables for the different correlations. The dependent variable, $\Delta\ln(C)$ (change in the logarithm of consumption, was regressed against:

$\Delta\ln(GNP_t)$ = change in the logarithm of real GNP from year t-1 to t

$\Delta\ln(P_t)$ = change in the logarithm of real price from year t-1 to t

$\Delta\ln(P_{t-i})$ = change in the logarithm of real price from year t-i-1 to t-i

Table 7-1 presents the results of these regressions for chlorine, total alkali, and soda ash consumption. Also included is the best-fit regression equation that describes the price of soda ash as a function of the price of caustic soda.

The coefficients of these regressions are estimates of the elasticities of chlorine, alkali, and soda ash consumption. This elasticity provides a measure of the percentage change in consumption that would result in the percentage change in the indicator variable. For instance, an income elasticity of 2.4 suggests that a 2.4% change in GNP would result in a 2.4% change in consumption. The elasticities estimated from this regression analysis are summarized in Table 7-2.

Table 7-1: Difference Model Regression Summary

1960 - 1989	1960 - 1974	1975 - 1989
Chlorine Consumption		
$\Delta\ln(C^{Cl}_t) = -0.048 + 2.4\,\Delta\ln(GNP_t) - 0.18\,\Delta\ln(P^{Cl}_{t-2})$	$\Delta\ln(C^{Cl}_t) = -0.017 + 1.2\,\Delta\ln(GNP_t)$	$\Delta\ln(C^{Cl}_t) = -0.079 + 3.0\,\Delta\ln(GNP_t) - 0.14\,\Delta\ln(P^{Cl}_{t-2})$
R^2adjusted = 60.6%	R^2adjusted = 28.6%	R^2adjusted = 76.7%
Alkali Consumption		
$\Delta\ln(C^{Alk}_t) = -0.029 + 1.7\,\Delta\ln(GNP_t) - 0.092\,\Delta\ln(P^{CS}_t)$	$\Delta\ln(C^{Cl}_t) = 0.0036 + 1.1\,\Delta\ln(GNP_t) - 0.18\,\Delta\ln(P^{CS}_t)$	$\Delta\ln(C^{Cl}_t) = -0.068 + 2.5\,\Delta\ln(GNP_t) - 0.16\,\Delta\ln(P^{CS}_{t-3})$
R^2adjusted = 50.2%	R^2adjusted = 51.6%	R^2adjusted = 59.0%
Soda Ash Consumption		
$\Delta\ln(C^{SA}_t) = -0.026 + 1.2\Delta\ln(GNP_t) - 0.077\,\Delta\ln(P^{CS}_{t-4}) - 0.068$ (1967 Shock)	$\Delta\ln(C^{SA}_t) = -0.009 + 0.88\,\Delta\ln(GNP_t) - 0.078\,\Delta\ln(P^{CS}_{t-1}) - 0.071$ (1967 Shock)	$\Delta\ln(C^{Cl}_t) = -0.038 + 1.6\,\Delta\ln(GNP_t) - 0.070\,\Delta\ln(P^{CS}_{t-4}) - 0.051$ (1984 Shock)
R^2adjusted =72.1%	R^2adjusted = 81.7%	R^2adjusted = 85.7%
Soda Ash Price		
$\Delta\ln(P^{SA}_t) = -0.0006 + 0.21\,\Delta\ln(P^{CS}_{t-1}) + 0.35\,\Delta\ln(P^{CS}_{t-5})$	$\Delta\ln(P^{SA}_t) = -0.035 - 0.72\,\Delta\ln(P^{CS}_{t-4})$	$\Delta\ln(P^{SA}_t) = -0.0096 + 0.19\,\Delta\ln(P^{CS}_{t-1}) + 0.38\,\Delta\ln(P^{CS}_{t-5})$
R^2adjusted =38.0%	R^2adjusted = 45.2%	R^2adjusted = 42.7%

Shock variables simply reduce the estimated change in the natural logarithm of consumption by the coefficient in the year of the shock.

Table 7-2: Elasticities of Chlorine, Total Alkali, and Soda Ash Consumption

	1960 to 1989	1960 to 1974	1960 to 1989
Chlorine Consumption			
Income Elasticity	2.4	1.2	3.0
Current Price Elasticity	0.0	0.0	0.0
Lagged Price Elasticity /Years Lag	-0.18/2	0.0	-0.14/2
Alkali Consumption			
Income Elasticity	1.7	1.1	2.5
Current Price Elasticity	-0.09	-0.18	0.0
Lagged Price Elasticity /Years Lag	0.0	0.0	-0.16/3
Soda Ash Consumption			
Income Elasticity	1.2	0.9	1.6
Current Price Elasticity	0.0	0.0	0.0
Lagged Price Elasticity/Years Lag	-0.08/4	-0.08/1	-0.07/4

7.1.1 Chlorine Consumption

Best-fit regression equations for chlorine consumption are given in Table 7-1. The income and price elasticities of chlorine consumption are summarized in Table 7-2. These regressions indicate that chlorine consumption was completely price inelastic during 1960 to 1974. The income elasticity was estimated to be 1.2 during this period, indicating that chlorine consumption grew slightly faster than GNP.

During 1975 to 1989, the income elasticity was estimated to be 3.0. Also, this correlation suggests that chlorine consumption this period is dependent only on the prices two and three years ago ($\Delta \ln (P^{Cl}{}_{t-2})$. This price elasticity is estimated to be only 0.14 which is relatively inelastic. Again, for many of the processes which use chlorine, there are few to no substitutes in the short-term. The demand for chlorine, therefore, should be relatively price inelastic. The lag effect of prices is most likely a function of the time that it takes chlorine users to respond to changes in the price. This lag in response could be due to the time to put engineering changes into effect in addition to the time it takes consumers to perceive a price change as being permanent.

A comparison of the 1960 to 1974 data set with the 1975 to 1989 data set indicates that chlorine has become more income elastic and more price elasticity. As previously mentioned, chlorine consumption consistently grew during 1960 to 1975 and then flatted as the industry matured during 1975 to 1989. While the industry was growing, the demand for chlorine was extremely strong and did not react to changes in price. Once the industry matured, however, the overall industry became much more dependent on the supply/demand balance which resulted in an increase in both income and price elasticities.

7.1.2 Alkali Consumption

The best-fit equations that describe total alkali consumption are given in Table 7-1. The income and price elasticities of total alkali consumption are summarized in Table 7-2. The correlation describing alkali consumption gave an income elasticity estimated to be 1.1 during the period 1960 to 1974. For the period 1975 to 1989, the income elasticity is estimated to have increased to 2.5. This significant increase may be the result of caustic soda and soda ash being used more and more as basic commodity chemicals and therefore becoming more dependent on the general economy as a whole.

Although the price elasticity has not changed much in magnitude, it has shifted from being an effect of the current price change to an effect of the price change three years ago. As with chlorine, this lag could be the result of the timing needed to put engineering changes into effect plus the time it takes consumers to perceive price changes as being permanent.

During the period 1960 to 1974, the industry was growing steadily and prices were falling consistently. Consumers could plan their consumption patterns based on the correct assumption that these trends would continue. But, during 1975 to 1989, these trends disappeared and planning based on continued trends was incorrect and led to sluggish reactions to price changes. Thus, the change from a growth market to a mature market led sluggish reactions to price changes.

7.1.3 Soda Ash Consumption

The best-fit correlations for soda ash consumption are shown in Table 7-1 with elasticities summarized in Table 7-2. These correlations show that soda ash demand during 1960 to 1974 was dependent on the general economy with an income elasticity of 0.9. As with chlorine and total alkali, the income elasticity of soda ash apparently increased during the study period, nearly doubling to 1.6 for the 1975 to 1989 period. This could be the result of soda ash becoming more and more of a true commodity chemical.

This correlation shows a clear relationship between soda ash supply and the price of caustic soda. During 1960 to 1974, soda ash demand showed a small negative elasticity (-0.08) to change in caustic soda price one year ago. During 1975 to 1989, this elasticity was similarly small (-0.07) but switched to being a function of the change in caustic soda price four years ago. Although only a small effect, changes in caustic soda prices are reflected in changes in soda ash demand. As caustic soda prices increase, soda ash suppliers can also charge higher prices. Demand will then decrease in response to these increased prices.

Finally, initial regressions of the data gave statistically significant outliers which indicated that some shocks occurred during 1967 and 1984 to give one-time shifts in soda ash demand. The shock in 1967 could have been the result of increasing rationalization of synthetic production as natural production became more common. Cuts in synthetic production were not always matched immediately with increases in natural production. As a result, changes in supply could have altered price and consumption more than expected.

The shock in 1984 was the result of a dramatic change in the pattern of caustic soda prices. In 1984, low chlorine demand led to lower production of both chlorine and caustic soda. Caustic soda demand, however, did not fall in proportion to the decline in chlorine demand. This led to a tight market for caustic soda and thus, higher caustic soda prices.

7.1.4 Caustic Soda/Soda Ash Price Relationship

Using the differenced model, changes in the real price of soda ash were regressed against changes in the price of caustic soda. The results of these regressions are given in Table 7-1. Overall, for the period 1960 to 1989, changes in the price of soda ash were correlated with changes in the price of caustic soda one year ago and five years ago. The correlation indicates that a 1% change in the caustic soda price one year ago would result in an 0.2% change in the price of soda ash today. Also, a 1% change in the caustic soda price five years ago would result in an 0.35% change in the price of soda ash today. Thus, the effect of changes in prices five years ago have more of an effect than changes in last years prices.

Soda ash price for the period 1960 to 1974 showed a similar relationship with only changes in caustic soda price four years ago being significant. The relationship suggests that a 1% change in caustic soda price four years ago will lead to an 0.7% change in soda ash price today. Finally, for the period 1975 to 1989, the relationship is similar to the overall relationship with changes in caustic soda prices one year ago and five years ago affecting soda ash price today.

Intuitively, these correlations indicate the timing at which the soda ash market reacts to changes in prices of caustic soda. When the price of caustic soda increases, soda ash becomes more economical to some alkali users and demand for soda ash rises. This change in demand, however, is not immediate. There will be those soda ash users that can use either caustic soda or soda ash without changing technology. These users will increase demand within one year and, as a result, suppliers will raise prices. Other alkali users that will switch will require a change in technology to use soda ash in place of caustic soda. This change will require planning, design, and implementation. The correlation suggests that this change takes approximately five years to come into effect. Thus, demand will increase five years after there is an increase in caustic soda price and soda ash suppliers will respond with their own price increase. These results agree quite well with the model of soda ash consumption. As discussed in section 7.1.3, soda ash consumption was shown to react to changes in caustic soda price one year ago and five years ago.

7.1.5 Summary of Differenced Regressions

Overall, the income elasticity of chlorine consumption has been slightly greater than that of total alkali consumption over the thirty year study period (1960 to 1989). More interestingly, the income elasticities of both chlorine and total alkali consumption have more than doubled from their levels during 1960 to 1974 to their levels during 1975 to 1989. The income elasticity of soda ash has been consistently less than that of both chlorine and total alkali and has also nearly doubled from its level during 1960 to 1974 to its level during 1975 to 1989. Price elasticities of chlorine and alkali consumption have been similar in magnitude throughout the period while chlorine consumption has generally reacted two to three years earlier than alkali and soda ash consumptions to changes in price. All of these price elasticities are small and indicate that chlorine, total alkali, and soda ash consumptions are relatively insensitive to price changes.

The large increase in income elasticity of all chemicals suggests that consumption has become more of a function of the overall level of the economy. During 1960 to 1974 the demand for all three chemicals could be described as consistently growing because of an increase in the uses for these chemicals. This growth, although linked somewhat to the overall economy, depended more on the increases in use. During 1975 to 1989, growth diminished as the industry matured. As such, demand became less of a function of growth and depended more strongly on the overall economy.

In general, the price elasticity of soda ash has been about half that of either chlorine or total alkali. With its strong export markets, soda ash has maintained more growth than either chlorine or caustic soda. This steadily increasing export demand has been relatively price insensitive and has therefore lowered the overall price sensitivity of soda ash.

Finally, soda ash and caustic soda prices are indeed closely related. This strong interaction is a result of the competition that exists between the two chemicals as they make up nearly all of the alkali market.

7.2 Time Series Analysis of Consumption

Based on the results of an analysis of the autocorrelation of chlorine, alkali, and soda ash consumption, and chlorine, caustic soda and ECU prices, it became quite evident that a significant time series trend existed in all of these variables. This analysis, presented in Appendix B, highlighted the following facts about the data:

1) The data sets of 1960 to 1974 and 1975 to 1989 are indeed quite different. This provides further support for separating the data when conducting the regression analysis.

2) During 1960 to 1974, all data show strong first lag positive autocorrelation and some nine to ten year lag negative autocorrelation. This suggests that there is some long-term cycle affecting the growth of consumption of these three chemicals.

3) During 1975 to 1989, all data show first year lag positive autocorrelation with some four year lag negative autocorrelation, followed by roughly eight year lag positive autocorrelation. This suggests that there is still some cycle affecting the consumption growth of these chemicals but that this cycle has now become shorter.

7.2.1 Chlorine Consumption Time Series Analysis

The best-fit time series regressions for chlorine consumption are given in Table 7-3. For the period 1960 to 1974, chlorine consumption showed a strong relationship to lagged chlorine consumption. This relationship was not statistically significant for the period 1975 to 1989. During a growth period, consumption would tend to be related to consumption in the last period, growing as some percentage of its past level. When growth slows or stops,

Table 7-3: Time Series Regressions of Consumption

1960 - 1989	1960 - 1974	1975 - 1989
Chlorine Consumption		
$\ln(C^{Cl}_t) = 0.64 + 0.93 \ln(C^{Cl}_{t-1})$ -0.026 (5 Yr Cycle Factor$_t$) -0.21 (1975 Shock) -0.20 (1982 Shock) Reference Year = 1960 R^2adjusted = 97.2%	$\ln(C^{Cl}_t) = 0.17 + 0.99 \ln(C^{Cl}_{t-1})$ -0.038 (5.5 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 98.4%	$\ln(C^{Cl}_t) = 9.22$ 0.082 (4.5 Yr Cycle Factor$_t$) -0.12 (1982 Shock) $+0.10$ (1984 Shock) Reference Year = 1961 R^2adjusted = 90.1%
Alkali Consumption		
$\ln(C^{Alk}_t) = 1.00 + 0.89 \ln(C^{Alk}_{t-1})$ -0.031 (5.5 Yr Cycle Factor$_t$) -0.17 (1975 Shock) Reference Year = 1960 R^2adjusted = 94.2%	$\ln(C^{Alk}_t) = 0.38 + 0.96 \ln(C^{Alk}_{t-1})$ -0.026 (5.5 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 97.2%	$\ln(C^{Alk}_t) = 5.2 + 0.45 \ln(C^{Alk}_{t-1})$ -0.041 (5.5 Yr Cycle Factor$_t$) -0.17 (1975 Shock) Reference Year = 1960 R^2adjusted = 57.9%
Soda Ash Consumption		
$\ln(C^{SA}_t) = 1.29 + 0.86 \ln(C^{SA}_{t-1})$ -0.017 (5.5 Yr Cycle Factor$_t$) -0.082 (1975 Shock) Reference Year = 1960 R^2adjusted = 89.0%	$\ln(C^{SA}_t) = 1.0 + 0.89 \ln(C^{SA}_{t-1})$ -0.016 (4 Yr Cycle Factor$_t$) Reference Year = 1960 R^2adjusted = 93.2%	$\ln(C^{SA}_t) = 6.61 + 0.25 \ln(C^{SA}_{t-1})$ -0.037 (6 Yr Cycle Factor$_t$) -0.062 (1975 Shock) Reference Year = 1960 R^2adjusted = 64.1%

N Yr Cycle Factor$_t$ = Cosine(π/N*(Year$_t$ - Reference Year))

Shock variables reduce the estimated change in the natural logarithm of consumption by the coefficient in the year of the shock.

this lagged dependance will diminish and consumption will be more related to an average level. Thus, the disappearance of the relationship between chlorine consumption and its lag is indicative of the decrease in growth as the industry matured.

Overall, the entire data set of chlorine consumption (1960 to 1989) exhibited a five-year cycle, fluctuating around the first lag in consumption.
Consumption during the period 1960 to 1974 showed a slightly longer cycle of 5.5 years while that of the period 1975 to 1989 exhibited a slightly shorter cycle of 4.5 years. In addition, the dependance of chlorine consumption on this cycle became stronger in 1975 to 1989. This is further evidence that the industry has matured with consumption varying more in a cycle and less through growth.

Thus, consumption of chlorine exhibits a roughly five year cycle between peaks and bottoms. Typically, the length of a cycle will depend on the ability of consumers to react to market pressures. It would appear that it takes major chlorine consumers approximately five years to modify their operations to either take advantage of using more chlorine or find ways of using less.

Another interesting result involves the presence of outliers in early regressions. These outliers suggest that "shocks" occurred in certain years that changed consumption beyond what might have been predicted by general trends. For chlorine consumption, three shocks were evident in the years 1975, 1982, and 1984.

As was discussed in Sections 4.1 and 7.1, the demand for chlorine is closely related to the state of the economy as a whole. All of these shocks occurred during periods of extreme change in GNP. As shown in Table 7-4, growth in real GNP in 1975, 1982, and 1984, was significantly different fro the general trend. During 1975 and 1982, the U.S. was in a period of recession which might have caused the use of chlorine to decline beyond what might have been expected from a general time-series trend. The dummy variables for these shocks, therefore show negative coefficients that predict one-time drops in consumption. Likewise, the upturn in 1984, caused by the dramatic increase in government spending may have caused chlorine consumption to increase more than the time-series trend would predict. The dummy variable for the 1984 shock, as expected, has a positive coefficient to account for the one-time increase in consumption.

During two of these shocks, 1975 and 1984, the growth of energy prices to the industrial sector changed dramatically. Table 7-4 shows that the growth in electricity prices to the industrial sector dramatically increased in 1974 and then fell in 1983. These changes apparently had some lagged effect on chlorine consumption. The large increase in energy prices in 1975 could have depressed the overall chemical industry which would have led to a drop in consumption. Likewise, the large drop in energy price growth in 1983 may have created a boost to the chemical industry, thereby increasing chlorine consumption.

Table 7-4: Economic Shocks During the Study Period

Year	Real GNP 1982 $, billions	GNP Growth	Industrial Sector Electricity Price $/MMBTU	Price Growth
1970	2416	3%	3.00	-
1971	2485	5%	3.22	7%
1972	2609	5%	3.41	6%
1973	2744	5%	3.65	7%
1974	2729	-1%	4.95	36%
1975	2695	-1%	6.05	22%
1976	2827	5%	6.46	7%
1977	2959	5%	7.34	14%
1978	3115	5%	8.21	12%
1979	3192	3%	8.96	9%
1980	3187	0%	10.81	21%
1981	3249	-1%	12.57	16%
1982	3166	-3%	14.51	15%
1983	3279	4%	14.54	0%
1984	3501	7%	14.16	-3%
1985	3619	3%	14.57	3%
1986	3718	3%	14.45	-1%
1987	3854	4%	13.98	-3%
1988	4024	4%	13.78	-3%
1989	4143	3%		

Sources:

Real GNP - Economic Report of the President to Congress, February 1990.

Industrial Sector Electricity Price - "State Energy Price Expenditure Report, 1970 - 1981", Energy Information Administration, U.S. Department of Energy, June 1984 and September 1990.

The magnitudes of these coefficients indicate the unexpected change in consumption as follows:

Year of Shock	Coefficient	Unexpected Change in Consumption
1975	-0.2	-18%
1982	-0.2	-18%
1984	0.1	+10%

Thus, significant downturns in the economy, like the one we are now experiencing, and drastic increases in the growth of energy prices will likely cause a significant unexpected drop in consumption. This drop would be on the order of 18% of the current level of consumption. On the other hand, booms and drastic increases in the growth of energy prices should cause consumption to jump. The economic boom of 1984 resulted in a 10% jump in consumption over normal levels for that time.

7.2.2 Total Alkali Consumption Time Series Analysis

Table 7-3 also includes the time series regression equations for alkali consumption. All regressions indicate that alkali consumption exhibits a 5.5 year cycle between demand peaks and bottoms and that consumption this period is a function of consumption last period (lagged consumption). Interestingly, however, alkali consumption showed a stronger relation to lagged consumption during the years 1960 to 1974 than it did during the years 1975 to 1989. Also, it would appear that cycles had more of an impact on alkali consumption during 1975 to 1989 than during 1960 to 1974. Like the chlorine industry, the alkali industry is maturing and growth is slowing.

Thus, the dependence on the lag has decreased while the dependance on a predictable cycle has become more important.

As with chlorine, economic shocks played a role in determining alkali consumption patterns. The only shock, however, that was statistically significant was the combined 1975 recession and 1974 energy price shock. This shock resulted in a 15% drop in alkali consumption below what might have been predicted if the shock had not occurred. Thus, it would appear that alkali consumption is sensitive to abrupt changes in the state of the economy, but somewhat less than that of chlorine. This supports the result given in Section 7-1 that showed the income elasticity of alkali to be slightly smaller than that of chlorine.

7.2.3 Soda Ash Consumption Time Series Analysis

The results of time series regressions of soda ash consumption are given in Table 7-3. Overall, for the entire study period (1960 to 1989), soda ash consumption showed a strong correlation to lagged consumption and followed a cycle about this lag of approximately 5.5 years. Soda ash consumption during the years 1960 to 1974 showed an equivalent relation to lagged consumption about a shorter cycle of 4 years. Finally, soda ash consumption during 1975 to 1989 showed a much weaker relation to lagged consumption and a stronger relation to a longer cycle of 6 years. This change to less dependance on lagged consumption and more on a stable cycle indicates that the industry is maturing and that growth is slowing.

Like total alkali, soda ash showed a statistical relation to only the 1975 recession of the study period. The coefficient of this dummy variable suggests that alkali was even less responsive to these recessions that was total alkali or chlorine. Soda ash consumption for 1975, due to the shock, was between 6% and 8% lower than it might have been if the shock had not occurred.

7.2.4 Summary of Time Series Consumption Analyses

Annual chlorine consumption, alkali consumption, and soda ash consumption were all strongly related to their levels in the previous year with elasticities ranging from 0.9 to 1.0 for the period 1960 to 1974. This relationship, however, became weaker during 1975 to 1989 for all three chemicals with the elasticity falling to zero for chlorine, 0.45 for alkali, and 0.25 for soda ash.

The consumption of all three chemicals also exhibited a predictable fluctuation around this lagged relationship that cycled over approximately five years for chlorine, 5.5 years for alkali, and 5.5 to 6 years for soda ash. Consumptions of chlorine, alkali, and soda ash all have become less dependent on lagged consumption and more dependant on a stable cycle. This indicates that the entire Chlor/Alkali industry has matured and that growth has virtually stopped.

Finally, economic shocks proved to significantly affect the variation of consumption of chlorine, alkali, and soda ash from the stable cycles. Chlorine was the most sensitive and was affected by shocks in 1975, 1982, and 1984. Total alkali and soda ash were somewhat less sensitive and responded with statistical significance to only the 1975 shock.

7.3 Time Series Analysis of Prices

Results of time-series regressions of chlorine, caustic soda, and ECU prices are given in Table 7-5. Like consumption, prices tended to be correlated with their levels in the previous year (lagged price) and varied about this lag with some predictable cycle. As before, the price of soda ash was assumed to be related to the price of caustic soda. This function is also included in Table 7-3.

7.3.1 Chlorine Price Time Series Analysis

Results of chlorine price time series regressions show that chlorine price is strongly related to the lag of chlorine price. The dependence with lagged price is slightly smaller for the period of 1975 to 1989 (elasticity of 0.76) than for the period 1960 to 1974 (elasticity of 0.91). Within standard error, the coefficients of lagged price are essentially the same for both periods.

The most interesting change, however, is the dependance on a cycle trend. Overall, chlorine price tended to vary with a four-year cycle around its lagged dependence. The regressions indicate that there was no cycle trend for the period 1960 to 1974 and a four-year cycle for the period 1975 to 1989. During 1960 to 1974, the chlorine industry was steadily growing and had not attained the cyclical behavior of a mature industry. After, 1975, however, the industry matured and developed a cycle of four years.

7.3.2 Caustic Soda Price Time Series Analysis

Table 7-5 also includes the time series regression results for the price of caustic soda. Like chlorine price, caustic soda shows a strong relationship with its level in the previous year (lagged price). The regression show that caustic soda price was slightly more dependent on its lag in the period 1975 to 1989

Table 7-5: Time Series Regressions of Real Prices

1960 - 1989	1960 - 1974	1975 - 1989
Chlorine Price		
$\ln(P^{Cl}_t) = -0.43 + 0.91 \ln(P^{Cl}_{t-1}) + 0.074 (4\ Yr\ Cycle\ Factor_t)$	$\ln(P^{Cl}_t) = 0.73 + 0.85 \ln(P^{Cl}_{t-1}) + 0.042 (9\ Yr\ Cycle\ Factor_t)$	$\ln(P^{Cl}_t) = 1.1 + 0.76 \ln(P^{Cl}_{t-1}) + 0.13 (4\ Yr\ Cycle\ Factor_t)$
Reference Year = 1960	Reference Year = 1960	Reference Year = 1960
R^2adjusted = 75.8%	R^2adjusted = 96.0%	R^2adjusted = 67.6%
Caustic Soda Price		
$\ln(P^{CS}_t) = 0.96 + 0.80 \ln(P^{CS}_{t-1}) - 0.010 (4\ Yr\ Cycle\ Factor_t) + 0.39 (1975\ Shock)$	$\ln(P^{CS}_t) = 1.24 + 0.74 \ln(P^{CS}_{t-1}) - 0.084 (4\ Yr\ Cycle\ Factor_t)$	$\ln(P^{CS}_t) = 0.80 + 0.84 \ln(P^{CS}_{t-1}) - 0.13 (4\ Yr\ Cycle\ Factor_t) + 0.40 (1975\ Shock)$
Reference Year = 1960	Reference Year = 1960	Reference Year = 1960
R^2adjusted = 63.5%	R^2adjusted = 73.7%	R^2adjusted = 51.5%
ECU Price		
$\ln(P^{ECU}_t) = 1.9 + 0.67 \ln(P^{ECU}_{t-1}) + 0.049 (8\ Yr\ Cycle\ Factor_t) + 0.20 (1975\ Shock)$	$\ln(P^{ECU}_t) = 1.63 + 0.71 \ln(P^{ECU}_{t-1}) + 0.051 (8\ Yr\ Cycle\ Factor_t)$	$\ln(P^{ECU}_t) = 2.1 + 0.62 \ln(P^{ECU}_{t-1}) + 0.052 (8\ Yr\ Cycle\ Factor_t) + 0.21 (1975\ Shock)$
Reference Year = 1960	Reference Year = 1960	Reference Year = 1960
R^2adjusted =82.5%	R^2adjusted = 75.2%	R^2adjusted = 78.1%
Soda Ash Price		
$\Delta\ln(P^{SA}_t) = -0.0006 + 0.21 \Delta\ln(P^{CS}_{t-1}) + 0.35 \Delta\ln(P^{CS}_{t-5})$	$\Delta\ln(P^{SA}_t) = -0.034 - 0.72 \Delta\ln(P^{CS}_{t-4})$	$\Delta\ln(P^{SA}_t) = -0.0096 + 0.19 \Delta\ln(P^{CS}_{t-1}) + 0.38 \Delta\ln(P^{CS}_{t-5})$
R^2adjusted =38.0%	R^2adjusted = 45.2%	R^2adjusted = 42.7%

N Yr Cycle $Factor_t$ = Cosine(π/N*($Year_t$ - Reference Year))
Shock variables reduce the estimated change in the natural logarithm of consumption by the coefficient in the year of the shock.

(elasticity of 0.84) than in the period 1960 to 1974 (elasticity of 0.74). Again, within standard errors, this difference is not significant.

Overall, caustic price varied with a four-year cycle around its lag. The dependance on this cycle increased slightly from an elasticity of -0.08 for the period 1960 to 1974 to -0.13 for the period 1975 to 1989. The length of the cycle, however, remained at four years throughout the entire thirty year data set. This consistency in price pattern, despite changes in consumption trends, indicates that the caustic soda prices vary based on the behavior of producers and their costs in an attempt to maintain a balanced supply. In addition, this variation has been fairly consistent throughout time and can therefore be used to estimate the future movements in real price.

The real price of caustic soda fluctuates with a negative elasticity to the four-year cycle while the real price of chlorine fluctuates with a positive elasticity to this cycle. This is expected as chlorine/caustic soda producers will increase the price of caustic soda when demand and price for chlorine are low and will increase the price of chlorine when the demand and price for caustic soda are low. Apparently, these changes occur in a roughly four-year pattern and are based on both consumer demand and producer reactions to maintain the return of the combined production of chlorine and caustic soda.

Finally, the 1975 shock was the only exogenous variable that proved to be statistically significant. This factor suggests that the price of caustic soda increased by more than 45% beyond what it would have been without the shock. This large increase could have been due to either the recession or the 1974 oil shock which substantially increased energy prices. Higher oil prices resulted in higher energy cost which is a significant portion of the total costs of chlorine and caustic soda production.

7.3.3 ECU Price Time Series Analysis

Overall, the ECU price showed a smaller price dependence on its lag than did chlorine and caustic soda and more of a dependence on a central mean (the constant of the regression analysis). One would expect this because chlorine and caustic soda are priced so that the combined ECU price will not vary much. Within standard errors, the three correlations of the real price of an ECU are essentially the same. This finding is quite interesting as it indicates that the factors affecting the price of an ECU have not changed over the thirty year study period. Despite changes in chlorine and caustic soda consumption trends, the ECU price trend has remained the same.

The combined ECU price tended to vary with an eight year cycle about its average price and lagged price. This is somewhat surprising in comparison to the four year cycles of chlorine and caustic soda prices. Producers of chlorine and caustic soda vary prices so that low chlorine prices are offset with high caustic soda prices and vice versa. The combined ECU pricing, however, is controlled by the total costs of production and the capacity in the industry. Thus, ECU pricing cycles will depend, mostly on supply-side factors such as the addition of new capacity and the rationalization of old. One can imagine that these changes in capacity will take longer to affect the ECU price than changes that affect chlorine and caustic soda prices. Thus, an eight year cycle is quite reasonable.

As with caustic soda, the 1975 shock was statistically significant in affecting the price of an ECU. The coefficient of this affect was essentially the same for the entire data set as it was for the subset of 1975 to 1989. With a coefficient of 0.2, this shock increased the price of an ECU by 22%. This shock was most likely due to the oil shock of 1974 which resulted in increased costs for chlorine/caustic soda producers.

7.3.4 Summary of Time Series Real Price Analyses

Overall, the price patterns for chlorine, caustic soda, and soda ash have all been fairly consistent over the entire thirty year data set. The price for chlorine, caustic soda and the combined ECU have all been strongly related to their prices in the previous year (lagged price). During 1975 to 1989, the lagged price elasticity of chlorine was approximately 0.76, for caustic soda, 0.84, and for the ECU, 0.62.

Both the real price of chlorine and the real price of caustic soda fluctuated about a predictable four year cycle while the combined ECU varied about an eight year cycle. Chlorine price, however, showed no cycle trend during 1960 to 1975 due to the steady growth in demand during that period.

Producers are able to vary chlorine and caustic soda prices to maintain a return on production and this variation occurs in response and in conjunction with changes in demand. The variation in the combined ECU price, however, varies with changes in production patterns such as the addition of new capacity and the rationalization of old. These changes in production patterns occur over a longer cycle of eight years.

Finally, of the two components of the ECU price, only the caustic soda price showed a statistically significant relationship with exogenous shocks. The 1974 oil shock and 1975 recession affected the 1975 costs of production which caused caustic soda price to increase by 45% beyond what it would have been without the shock. This translated to a 22% increase in the price of an ECU.

CHAPTER 8

FORECASTING DEMAND AND PRICES

The model can now be used to project the demand and prices of chlorine, total alkali, soda ash, and caustic soda. In general, the model is useful in assessing how changes in the economy and time will affect the general trend in prices and consumption. The model should not, however, be relied upon as an exact predictor of prices and consumption. Its main benefit is that it can be used to predict general trends such as when demand can be expected to slow in growth or when prices will recover.

8.1 Projected Price Trends

The time series model is the simplest model to use to project real price trends because it does not require the forecasting of other indicator variables such as GNP. With the inclusion of cycle terms, this model provides an estimate of when the short term growth/decline in prices and consumption will turn around. Using the time series model, the real prices of caustic soda, chlorine, the ECU, and soda ash were calculated and compared to historic prices. These prices are plotted in Figures 8-1 through 8-3.

The fact that predicted values fall closely to actual values indicates that this model does indeed provide an accurate mathematical description of the industry. In addition, predicted prices were projected out to 1994 to provide a forecast of the trends in the industry. Table 8-1 provides a summary of these price projections.

Figure 8-1: Actual and Predicted Real Chlorine and Caustic Soda Prices

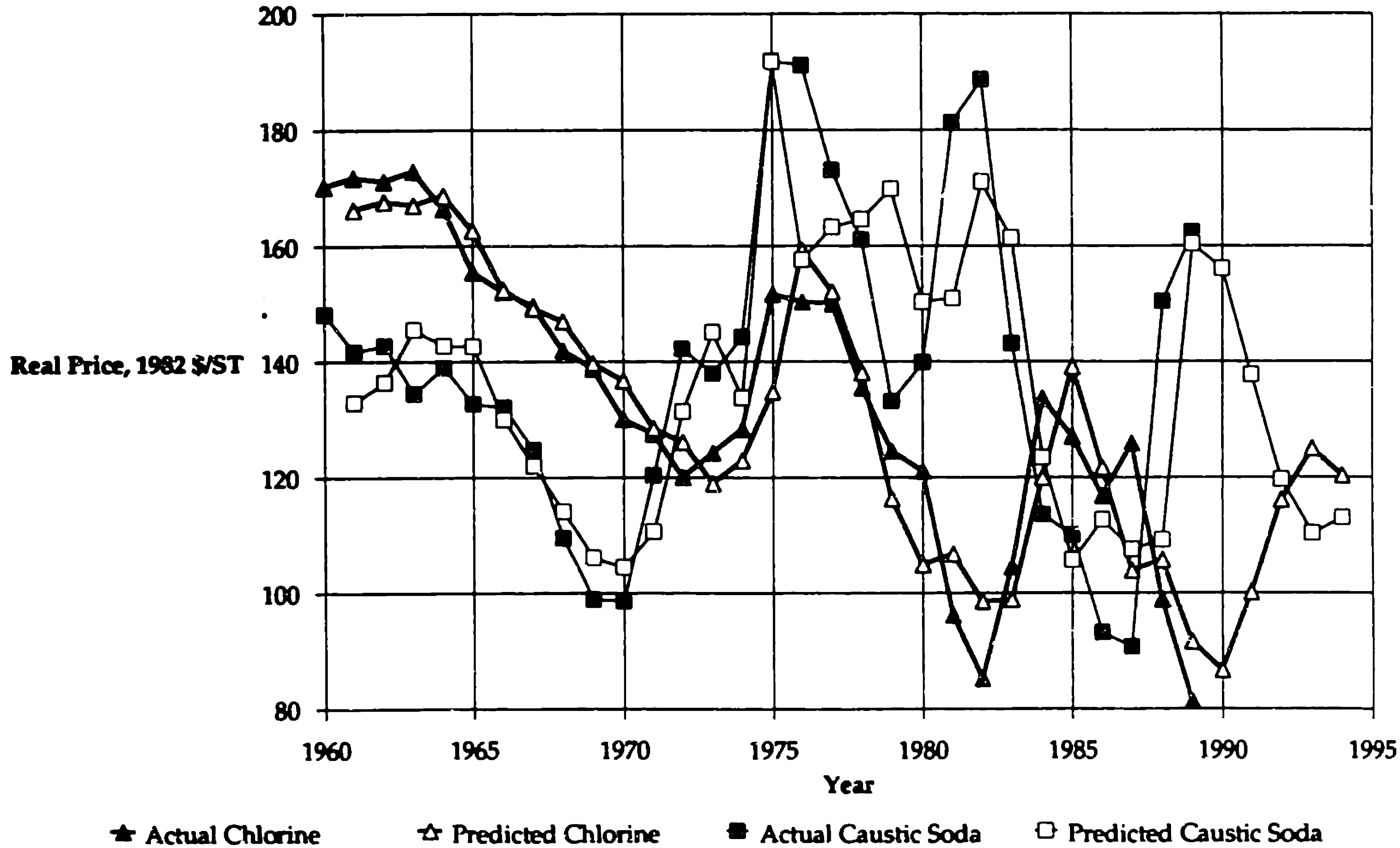


Figure 8-2: Actual and Predicted Real ECU Price

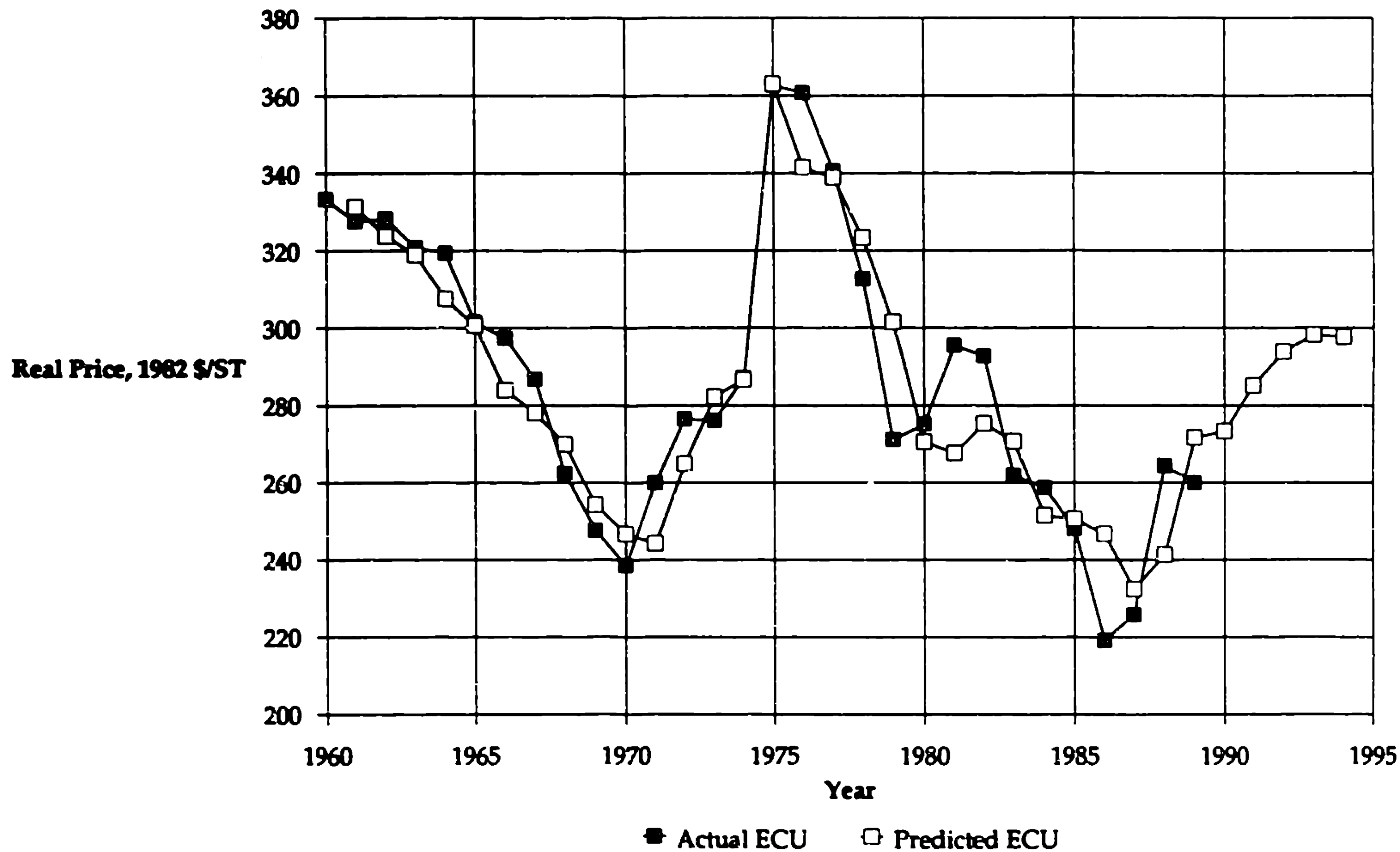


Figure 8-3: Actual and Predicted Real Soda Ash Price

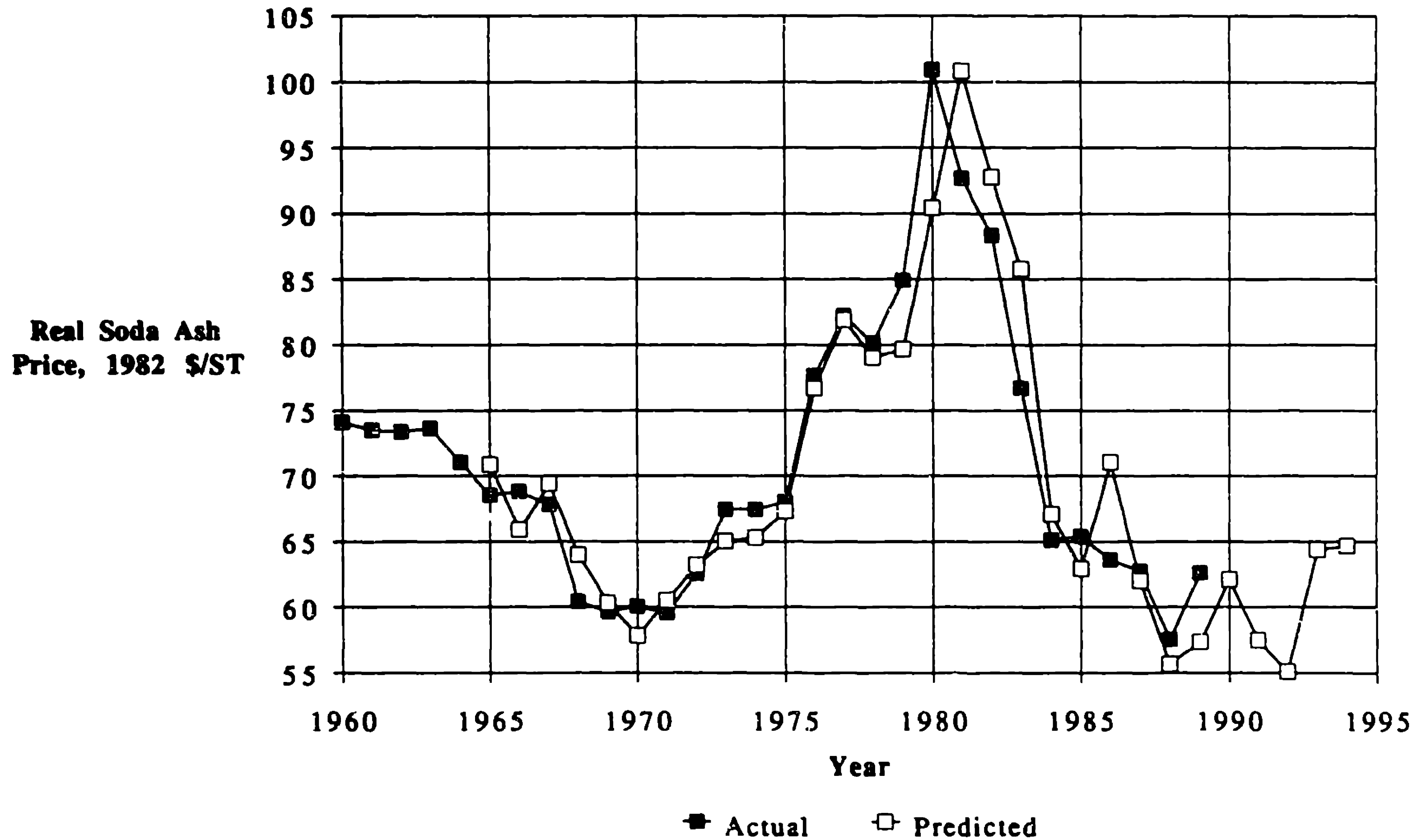


Table 8-1: Real Price Forecasts for Chlorine, Caustic Soda, ECU, and Soda Ash

	Real Price, 1982 $*				
	1990	1991	1992	1993	1994
Chlorine	87	100	116	125	120
Caustic Soda	156	138	120	110	113
ECU	273	285	294	298	293
Soda Ash	62	57	54	63	64

*Conversion to nominal prices can be made using the Chemical Industry Producer Price Index, from the Economic Report of the President to Congress

The highlights of these projections include:

- The real price of chlorine will fall again in 1990 and then rebound through 1993, peaking at approximately $125/ST (1982 dollars). The currently low price of chlorine will cause incremental users to increase demand, which will cause price to rise. Additionally, the low current low price of chlorine makes alternate chlorine production technologies uneconomical. These producers will shutdown, which will decrease capacity and supply, and put pressure on the price of chlorine.

- The real caustic soda price will start to fall and will hit a low of around $110/ST (1982 dollars) in 1993. The currently high price of caustic soda is causing incremental users to switch to soda ash. This drop in demand will put downward pressure on the price of caustic soda. In addition, a rising chlorine price will increase the return on the ECU and will allow chlorine/caustic soda producers to lower caustic soda price.

- The ECU real price will continue to rebound over the next four years and should peak at approximately $298/ST (1982 dollars) by 1993. Although the price of caustic soda is high, it is not completely compensating the extremely low chlorine price. The current return on the co-production of chlorine and caustic soda is therefore poor and producers are rationalizing capacity. As capacity falls, industry utilization rises and pressure mounts to raise the price of the combined ECU.

- Comparing the forecasts for the price of caustic soda and the price of chlorine shows that by 1992, the prices of chlorine and caustic soda will be roughly the same. By 1993, the price of chlorine may actually surpass that of caustic soda for one to two years. At this point, the relatively high price of chlorine will cause demand to fall and prices will follow while the low price of caustic soda will raise demand and lower price.

- The real price of soda ash will decline over the next two to three years to approximately $54/ST (1982 $) and will then rebound through 1994 to roughly $64/ST. In general, the real price of soda ash will continue to slowly cycle between $55/ST and $65/ST as the supply/demand balance for alkali cycles in response.

8.2 Projected Consumption Trends

Again, using the time series analysis, predicted consumptions of chlorine, caustic soda, soda ash, and total alkali were plotted with their actual values in Figures 8-4 through 8-7. The close fit between the predicted and actual values of consumption gives further evidence that this model provides and accurate mathematical description of the industry.

The model was used to predict the levels of consumption that might be expected through 1994. Figures 8-4 through 8-7 also includes the values of these projections. Table 8-2 summarizes these projections.

Table 8-2: Consumption Forecasts for Chlorine, Caustic Soda, Soda Ash, and Total Alkali

	Annual Consumption, M-ST				
	1990	1991	1992	1993	1994
Chlorine	10,200	9,800	9,300	9,300	9,600
Caustic Soda	10,700	10,200	9,700	9,400	9,300
Soda Ash	7,300	7,300	7,200	7,000	6,900
Total Alkali	12,300	12,000	11,600	11,200	11,000

The following predictions can be made about the consumption of chlorine, caustic soda, soda ash, and total alkali.

- Chlorine consumption will fall over the next few years and by 1993 should decline to roughly 9,300 M-ST per year. The rationalization

Figure 8-4: Actual and Predicted Chlorine Consumption

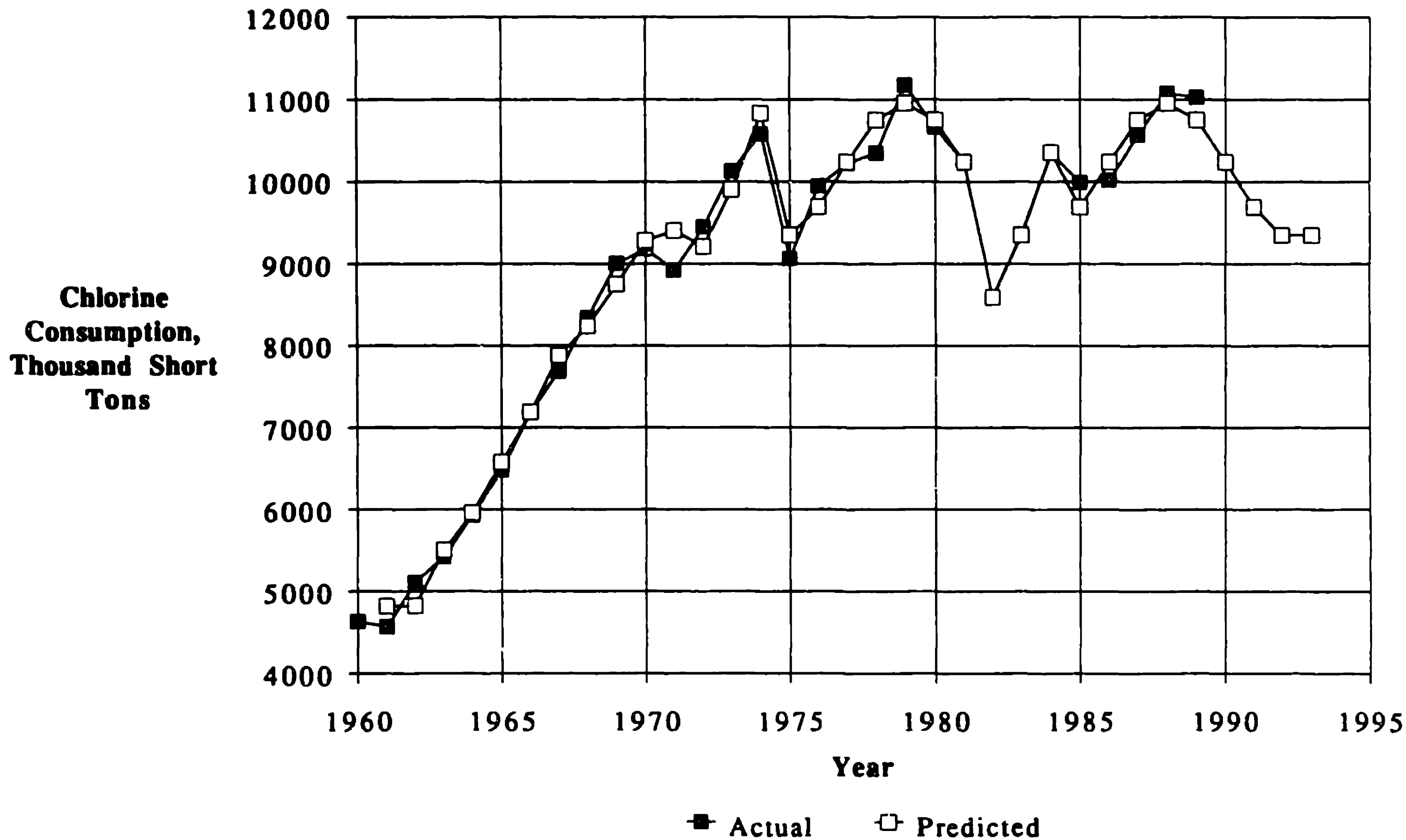


Figure 8-5: Actual and Predicted Caustic Soda Consumption

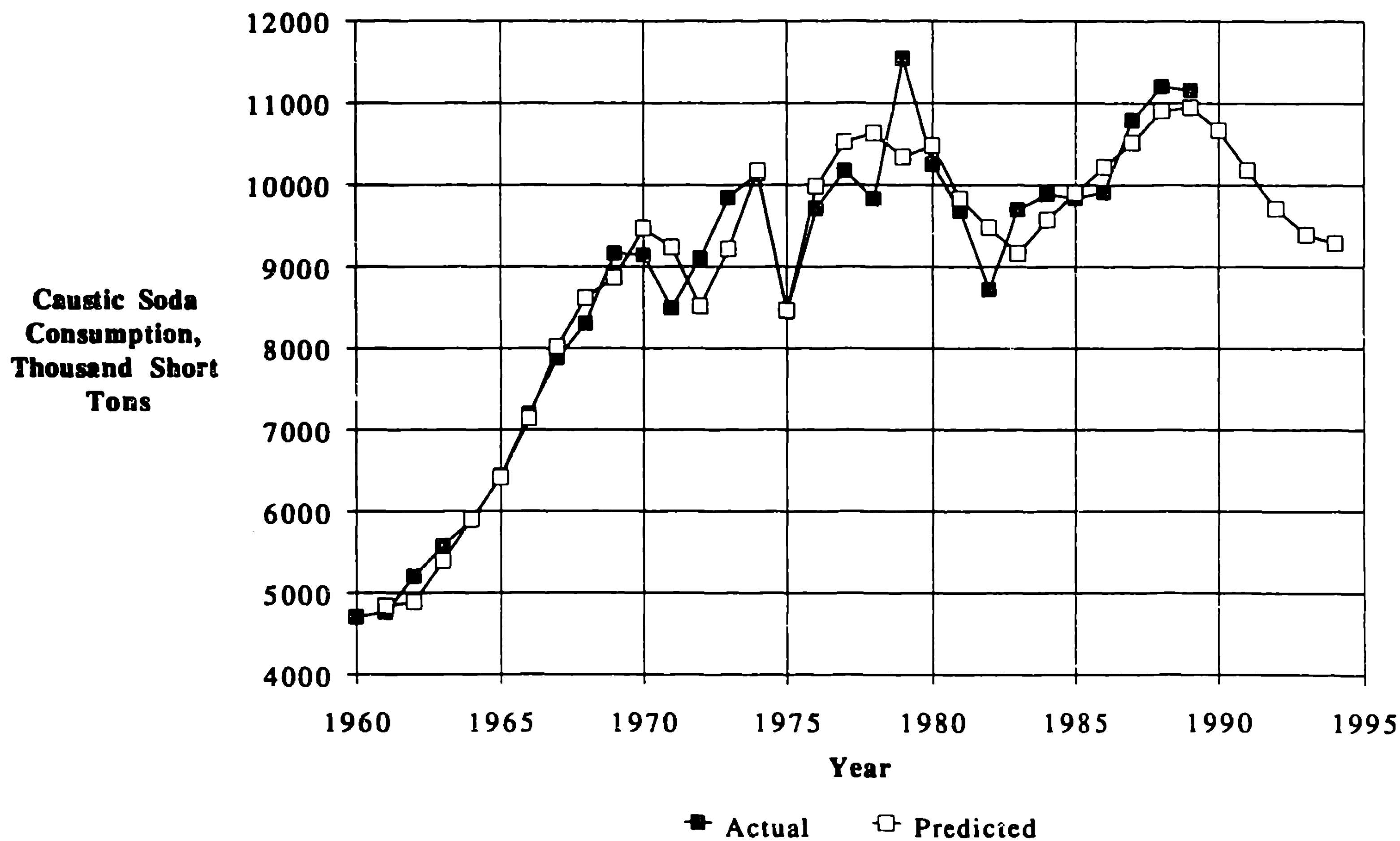


Figure 8-6: Actual and Predicted Soda Ash Consumption

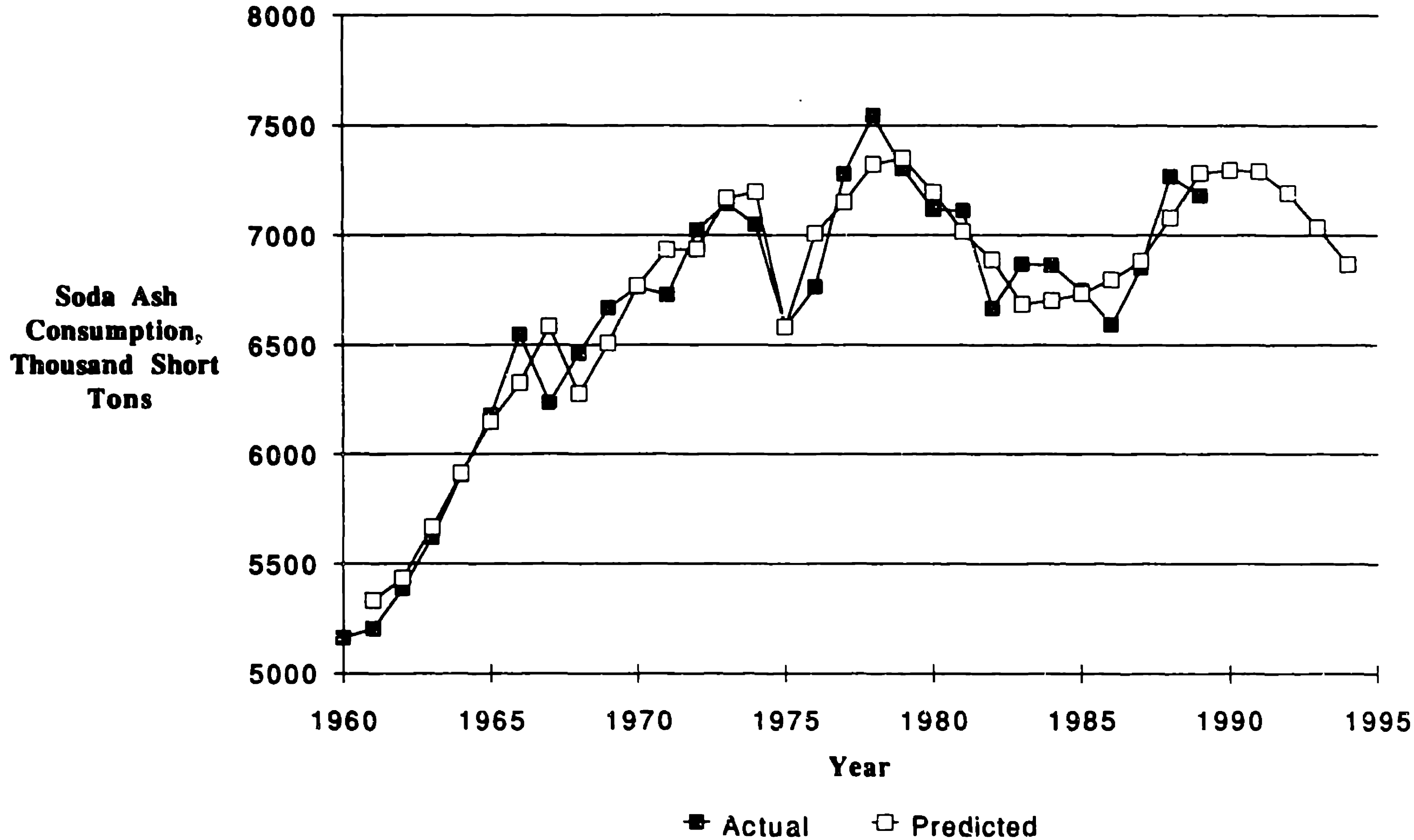
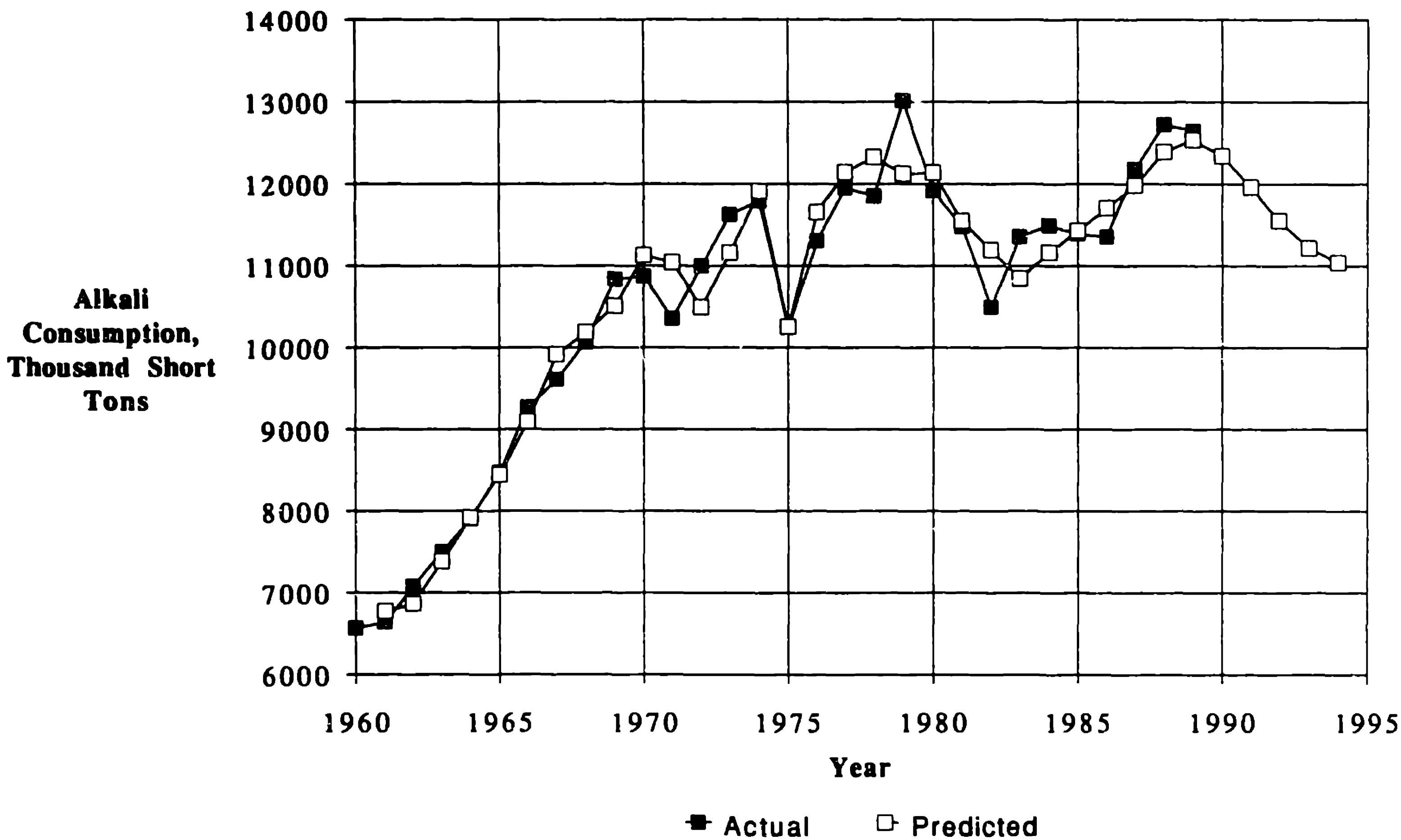


Figure 8-7: Actual and Predicted Alkali Consumption



of chlorine/caustic soda production capacity will lead to price increases which will cause marginal chlorine consumers to cut back consumption.

- Caustic soda consumption will continue to decline over the next few years and by 1994, should fall to approximately 9,300 M-ST per year. This decline is the result of the currently high prices that now exist. Over time, the fall in demand will slow as the price of caustic soda falls.

- Soda ash consumption will remain fairly stable over the next couple of years at 7,300 M-ST and will then fall to approximately 6,900 M-ST by 1993.

- Total alkali consumption showed signs of decline in 1989 and should continue to decline for the next four years, falling to approximately 11,000 M-ST per year. The past increases in the prices of both caustic soda and soda ash will cause a drop in alkali demand which, because of lagged responses to prices, will continue over the next several years.

- The recession will potentially worsen all of these declines depending upon its magnitude.

These models rely on a mathematical trend that was evident in the past. They do not specifically address shocks to the industry such as drastic changes in regulations that may severely impact demand or costs of production. In addition, although the model for consumption does not specifically include the effect of prices on consumption, consumption can be statistically predicted with price and vice versa so that their effects can be separated out of the equation. The effect of an exogenous price or demand shock can be evaluated using the differenced regression model which provides estimates of the price and income elasticities of consumption.

APPENDIX A

STRAIGHT LOGARITHMIC REGRESSION ANALYSIS

A.1 Chlorine Consumption

The initial hypothesis was that chlorine consumption in the U.S. varies as some function of income (GNP), price, and the lags of price. Data was regressed in two sub-sets which included the periods 1960 to 1974 and 1975 to 1989. These subsets were regressed against GNP, price and lags of price using a step wise regression technique. The natural logarithms of variables were used in the regression because they give coefficients that are equal to the elasticities of consumption with respect to each variable. In addition, real values (1982 dollars) were used for GNP and prices. Using only those variables that remain significant (t-ratio greater than 2), the results of these regressions are as follows:

DATA SET 1960 - 1974

$$\ln(C^{Cl}_t) = -4.42 + 1.73\ln(GNP_t)$$

R^2adj = 98.7

where:

C^{Cl}_t = Chlorine consumption during year t

GNP_t = Real GNP during year t

This regression appears to fit the data quite well. The residuals from this regression, however, demonstrate a significant trend, following some cyclical pattern. In addition, the Durbin-Watson Statistic of the regression indicates that the data set may be autocorrelated. Based on this, a lagged consumption variable was added to yield:

$$\ln(C^{Cl}_t) = -2.82 + 1.09\ln(GNP_t) + 0.374\ln(C^{Cl}_{t-1})$$

$R^2adj = 99.1$

This regression shows significantly more variability in the residuals than the original regression.

In either case, chlorine consumption during this period demonstrated no price elasticity. This may be expected as chlorine is a crucial component in several chemical operations such as PVC production, paper bleaching, and water treatment. In the short term, it is nearly impossible to modify operations or find substitutes to reduce chlorine demand.

DATA SET 1975 - 1989

Again, using stepwise regression of chlorine consumption versus Real GNP, price, and its lags gives the following correlation:

$$\ln(C^{Cl}_t) = -1.37 + 0.84\ln(GNP_t) + 0.34\ln(P^{Cl}_t) + 0.14\ln(P^{Cl}_{t-1}) + 0.31\ln(P^{Cl}_{t-4}) + 0.25\ln(P^{Cl}_{t-6}) - 0.25\ln(P^{Cl}_{t-7})$$

$R^2adj = 90.1$

where:

P^{Cl}_t = Annual average real chlorine price in year t

This regression appears to be somewhat complicated. It suggests that chlorine consumption depends no only on income but also on several lags of prices.

More interestingly, it would appear that chlorine consumption is positively correlated with price. The last two terms show that this periods consumption is positively correlated with the *change* in price from the seventh to the sixth year ago. It is hard to imagine how consumption would increase (decrease) as price increased (decreased). This suggests that demand was undergoing some fundamental change during the period and that both price and consumption were declining due to a shift reduction in demand. One possibility might be the increased environmental pressure to reduce the use of chlorinated compounds.

This correlation suggests that a differenced model might provide a better description of the industry.

A.2 Alkali Consumption

As with chlorine, it was assumed that total alkali consumption could be described using income (GNP), price of caustic soda, and its lags. The price of caustic soda was used because it is believed to be the driver for the industry. The soda ash portion of alkali has followed the demand for caustic soda. As caustic soda demand rises and caustic prices rise, more users of alkali will switch from caustic soda to soda ash. Thus, demand for soda ash will follow demand for caustic soda. In addition, as the demand for soda ash rises, its price will also rise and production will increase tapping those mines that are marginally more costly to produce.

As with chlorine, it was clear that the alkali data set can be broken down into two subsets; 1960 to 1974, and 1975 to 1989. Pressures that affected chlorine obviously affected alkali in a similar manner. This is not surprising since the two chemicals are co-produced and their prices are therefore linked.

Regressing data against real GNP, prices, and price lags gave the following results:

DATA SET 1960 - 1974

$$\ln(C^{Alk}_t) = 1.19 + 1.17\ln(GNP_t) - 0.170\ln(P^{CS}_t)$$

$R^2adj = 99.4$

Although small, alkali consumption did exhibit some price elasticity during the period 1960 to 1974. One could imagine that alkali is not as crucial to a chemical operation as is chlorine. Thus, as price increases, chemical manufacturers can either economize and use less, alter the process, or simply find some other substitute. This causes the demand for alkali to therefore exhibit some price elasticity. Again, this is a small effect with an elasticity of only 0.17.

DATA SET 1975 - 1989

$$\ln(C^{Alk}_t) = 6.63 + 0.483\ln(GNP_t) - 0.24\ln(P^{CS}_{t-9})$$

$R^2adj = 69.3$

where:

C^{Alk}_t = Alkali consumption during year t

P^{CS}_t = Annual average real caustic soda price in year t

This correlation shows some significant differences compared with the 1960 to 1974 correlation. First, the income elasticity has apparently dropped from 1.17 to only 0.48. This suggests that growth of caustic use, therefore, does not grow as rapidly as it had in the past. During 1960 to 1974, caustic demand grew at about the same rate as the economy. Over the last fifteen years, however, this growth has apparently slowed to only about 50% of the growth in the economy. Apparently, some other technology must be replacing alkali either in new operations or in old ones.

Second, the effect of prices has changed from a correlation with this year's price to a correlation with the price nine years ago. Although still small, the nine-year-ago price elasticity of 0.24 is larger than the current price elasticity determined for the 1960 to 1974 period.

A.3 Soda Ash Supply

Finally, the variation of soda ash supply with GNP, caustic soda price, and its lags was determined. This relationship can then be subtracted to determine the caustic soda demand net of soda ash supply. The results of the regression analysis is as follows:

DATA SET 1960 - 1974

$$\ln(S^{SA}{}_{t}) = 12.0 - 0.273\ln(P^{SA}{}_{t-1}) - 0.487\ln(P^{SA}{}_{t-4})$$

R^2adj = 86.1%

This suggests that soda ash did not respond, in general, to changes in income. Rather it responded basically to the prices that could be received from selling the material. This regression suggests that the supply of soda ash dropped slightly with last year's prices and prices four years ago. Last year's price elasticity is the short-term reaction to changes in price. The price four years ago represents the long-term price reaction. A change in any given year will result in an attempt to alter production and exploration which will take several years to bring about.

DATA SET 1975 - 1989

$$\ln(S^{SA}_{t}) = 6.72 + 0.304\ln(GNP_{t}) + 0.152\ln(P^{SA}_{t-1}) - 0.230\ln(P^{SA}_{t-5})$$

$R^2adj = 42.5\%$

Interestingly, this correlation suggest that soda ash supply varied as a function of GNP during the period 1975 - 1989, whereas it did not in the 1960 - 1974 period. Also, the supply now reacts positively to increases in last year's price. This is may be expected because price increases will cause an increase in capacity due to the start-up of marginally profitable mines. Finally, the long-term price elasticity is still negative but has dropped significantly and has moved back to the fifth price lag.

APPENDIX B

AUTOCORRELATION OF VARIABLES

The regression analysis has shown that the demands for chlorine, caustic soda, and soda ash are strongly tied with GNP. Since GNP has grown in a relatively stable pattern, it tends to show autocorrelation with itself. Figure B-1 shows the autocorrelation pattern of GNP with itself which indicates that this year's GNP is strongly autocorrelated with last year's GNP and that it is negatively correlated with GNP in the distant past (approximately twenty years ago). Thus, because GNP is strongly autocorrelated, one would expect the demands (and possibly prices) for chlorine, caustic soda, and soda ash to also be autocorrelated.

B.1 Chlorine Autocorrelations

The autocorrelation functions for chlorine consumption are given in Figure B-2. These data were analyzed in two subsets as was done in the regression analyses. For 1960 to 1974, chlorine consumption shows significant positive autocorrelation with last year's consumption. Also, it shows negative autocorrelation with chlorine consumption of approximately nine years ago. This indicates that there was some cyclical pattern to the growth in chlorine consumption.

Analysis of the 1974 to 1989 data set shows a strong cyclical trend in chlorine consumption. After a positive first lag autocorrelation, chlorine consumption showed a negative fourth year lag autocorrelation, then a positive eighth year lag, then a negative twelfth year lag. This suggest that

Figure B-1: Autocorrelation Function of Real GNP

```
              N     MEAN   MEDIAN   TRMEAN    STDEV   SEMEAN      MIN      MAX
ln(GNP)      30   7.9046   7.9144   7.9095   0.2583   0.0472   7.4176   8.3292


ACF of ln(GNP)

          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.881                          XXXXXXXXXXXXXXXXXXXXXXX
  2   0.759                          XXXXXXXXXXXXXXXXXXXX
  3   0.647                          XXXXXXXXXXXXXXXXX
  4   0.542                          XXXXXXXXXXXXXXX
  5   0.445                          XXXXXXXXXXXX
  6   0.357                          XXXXXXXXXX
  7   0.289                          XXXXXXXX
  8   0.225                          XXXXXXX
  9   0.156                          XXXXX
 10   0.091                          XXX
 11   0.016                          X
 12  -0.057                         XX
 13  -0.116                       XXXX
 14  -0.159                      XXXXX
 15  -0.198                     XXXXXX
 16  -0.252                    XXXXXXX
 17  -0.301                  XXXXXXXXX
 18  -0.333                  XXXXXXXXX
 19  -0.346                 XXXXXXXXXX
 20  -0.352                 XXXXXXXXXX
 21  -0.365                 XXXXXXXXXX
 22  -0.374                 XXXXXXXXXX
 23  -0.387                XXXXXXXXXXX
 24  -0.390                XXXXXXXXXXX
 25  -0.368                 XXXXXXXXXX
 26  -0.328                  XXXXXXXXX
 27  -0.273                   XXXXXXXX
 28  -0.201                     XXXXXX
 29  -0.107                       XXXX
```

Figure B-2: Autocorrelation Functions of Chlorine Consumption

Data Set 1960 - 1974

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(C^{Cl})$	15	8.8867	8.9468	8.8928	0.2888	0.0746	8.4268	9.2670

ACF of $\ln(C^{Cl})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.823                          XXXXXXXXXXXXXXXXXXXXXX
  2   0.609                          XXXXXXXXXXXXXXXX
  3   0.423                          XXXXXXXXXXXX
  4   0.244                          XXXXXXX
  5   0.056                          XX
  6  -0.116                       XXXX
  7  -0.246                    XXXXXXX
  8  -0.342                 XXXXXXXXXX
  9  -0.399                XXXXXXXXXXX
 10  -0.401                XXXXXXXXXXX
 11  -0.380                 XXXXXXXXXX
 12  -0.348                 XXXXXXXXXX
 13  -0.278                   XXXXXXXX
 14  -0.145                      XXXXX
```

Data Set 1975 - 1989

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(C^{Cl})$	15	9.2254	9.2348	9.2309	0.0741	0.0191	9.0584	9.3213

ACF of $\ln(C^{Cl})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.387                          XXXXXXXXXXX
  2  -0.110                       XXXX
  3  -0.278                   XXXXXXXX
  4  -0.294                   XXXXXXXX
  5  -0.255                    XXXXXXX
  6  -0.272                   XXXXXXXX
  7   0.106                          XXXX
  8   0.226                          XXXXXXX
  9   0.146                          XXXXX
 10   0.156                          XXXXX
 11   0.037                          XX
 12  -0.075                        XXX
 13  -0.151                      XXXXX
 14  -0.122                       XXXX
```

chlorine consumption growth followed some four year cycle in the period 1975 to 1989.

Figure B-3 shows the autocorrelation functions for the real price of chlorine. The patterns in real price are similar to those of consumption. For the data set 1960 to 1974, the real price of chlorine shows strong first lag autocorrelation and some ninth lag autocorrelation. For the data set 1974 to 1989, the data shows the roughly four year cycle as exhibited with consumption.

B.2 Alkali Autocorrelations

The autocorrelation functions for alkali consumption are given in Figure B-4. As with chlorine, alkali consumption during 1960 to 1974 shows significant first year lag positive autocorrelation and tenth year negative autocorrelation. Alkali consumption in 1975 to 1989, like chlorine consumption, exhibited some cycle in autocorrelation. This cycle appeared to be somewhat longer, with swings in autocorrelation of four to five years.

Autocorrelation functions for the real price of caustic soda are given in Figure B-5. For the data set 1960 to 1974, caustic price showed strong first year lag positive autocorrelation and some negative autocorrelation between the fifth and ninth year lags. For the data set 1975 to 1989, real caustic soda price shows a cyclical autocorrelation, with swings of four to five years.

B.3 Soda Ash Autocorrelations

Autocorrelation functions for soda ash are given in Figure B-6. During 1960 to 1974, soda ash, like chlorine and alkali, showed strong first year lag

Figure B-3: Autocorrelation Functions of Real Price of Chlorine

Data Set 1960 - 1974

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(P^{Cl})$	15	4.9897	5.0086	4.9927	0.1317	0.0340	4.7875	5.1527

ACF of $\ln(P^{Cl})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.874                          XXXXXXXXXXXXXXXXXXXXXXX
  2   0.689                          XXXXXXXXXXXXXXXXXX
  3   0.452                          XXXXXXXXXXXX
  4   0.223                          XXXXXXX
  5   0.007                          X
  6  -0.144                      XXXXX
  7  -0.282                   XXXXXXXX
  8  -0.391                XXXXXXXXXXX
  9  -0.455               XXXXXXXXXXXX
 10  -0.474              XXXXXXXXXXXXX
 11  -0.412                XXXXXXXXXXX
 12  -0.316                  XXXXXXXXX
 13  -0.189                     XXXXXX
 14  -0.082                        XXX
```

Data Set 1975 - 1989

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(P^{Cl})$	15	4.7711	4.8251	4.7805	0.2002	0.0517	4.3969	5.0226

ACF of $\ln(P^{Cl})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.551                          XXXXXXXXXXXXXXX
  2   0.085                          XXX
  3  -0.077                        XXX
  4  -0.261                   XXXXXXXX
  5  -0.308                  XXXXXXXXX
  6  -0.087                        XXX
  7   0.156                          XXXXX
  8   0.162                          XXXXX
  9   0.064                          XXX
 10  -0.024                         XX
 11  -0.146                      XXXXX
 12  -0.208                     XXXXXX
 13  -0.241                    XXXXXXX
 14  -0.168                      XXXXX
```

Figure B-4: Autocorrelation Functions of Alkali Consumption

Data Set 1960 - 1974

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(C^{Alk})$	15	9.1196	9.1708	9.1252	0.2046	0.0528	8.7904	9.3754

ACF of $\ln(C^{Alk})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.816                          XXXXXXXXXXXXXXXXXXXXX
  2   0.599                          XXXXXXXXXXXXXXXX
  3   0.413                          XXXXXXXXXXX
  4   0.245                          XXXXXXX
  5   0.049                          XX
  6  -0.127                       XXXX
  7  -0.241                    XXXXXXX
  8  -0.336                  XXXXXXXXX
  9  -0.400                XXXXXXXXXXX
 10  -0.391                XXXXXXXXXXX
 11  -0.363                 XXXXXXXXXX
 12  -0.347                 XXXXXXXXXX
 13  -0.275                   XXXXXXXX
 14  -0.144                      XXXXX
```

Data Set 1975 - 1989

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(C^{Alk})$	15	9.3649	9.3499	9.3666	0.0659	0.0170	9.2345	9.4737

ACF of $\ln(C^{Alk})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.377                          XXXXXXXXXX
  2  -0.025                         XX
  3  -0.307                  XXXXXXXXX
  4  -0.350                 XXXXXXXXXX
  5  -0.246                    XXXXXXX
  6  -0.176                      XXXXX
  7   0.033                          XX
  8   0.135                          XXXX
  9   0.228                          XXXXXXX
 10   0.248                          XXXXXXX
 11   0.090                          XXX
 12  -0.105                       XXXX
 13  -0.228                    XXXXXXX
 14  -0.172                      XXXXX
```

Figure B-5: Autocorrelation Functions of Real Price of Caustic Soda

Data Set 1960 - 1974

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(P^{CS})$	15	4.8587	4.9019	4.8684	0.1334	0.0345	4.5914	4.9991

ACF of $\ln(P^{CS})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.714                          XXXXXXXXXXXXXXXXXXX
  2   0.299                          XXXXXXXX
  3  -0.116                       XXXX
  4  -0.299                   XXXXXXXX
  5  -0.312                  XXXXXXXXX
  6  -0.273                   XXXXXXXX
  7  -0.253                    XXXXXXX
  8  -0.265                   XXXXXXXX
  9  -0.228                    XXXXXXX
 10  -0.090                        XXX
 11   0.048                          XX
 12   0.129                          XXXX
 13   0.082                          XXX
 14   0.064                          XXX
```

Data Set 1975 - 1989

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(P^{CS})$	15	4.9710	5.0138	4.9846	0.2521	0.0651	4.5087	5.2567

ACF of $\ln(P^{CS})$

```
          -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
            +----+----+----+----+----+----+----+----+----+----+
  1   0.641                          XXXXXXXXXXXXXXXXX
  2   0.147                          XXXXX
  3  -0.078                        XXX
  4  -0.191                     XXXXXX
  5  -0.136                       XXXX
  6   0.059                          XX
  7   0.103                          XXXX
  8  -0.117                       XXXX
  9  -0.318                  XXXXXXXXX
 10  -0.326                  XXXXXXXXX
 11  -0.263                   XXXXXXXX
 12  -0.110                       XXXX
 13   0.052                          XX
 14   0.038                          XX
```

Figure B-6: Autocorrelation Functions of Soda Ash Consumption

Data Set 1960 - 1974

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(C^{SA})$	15	8.7384	8.7737	8.7425	0.1108	0.0286	8.5493	8.8743

ACF of $\ln(C^{SA})$

```
             -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
               +----+----+----+----+----+----+----+----+----+----+
     1   0.800                          XXXXXXXXXXXXXXXXXXXXX
     2   0.565                          XXXXXXXXXXXXXXX
     3   0.348                          XXXXXXXXXX
     4   0.172                          XXXXX
     5   0.009                          X
     6  -0.095                        XXX
     7  -0.136                       XXXX
     8  -0.235                    XXXXXXX
     9  -0.346                 XXXXXXXXXX
    10  -0.392                XXXXXXXXXXX
    11  -0.399                XXXXXXXXXXX
    12  -0.378                 XXXXXXXXXX
    13  -0.278                   XXXXXXXX
    14  -0.135                       XXXX
```

	N	MEAN	MEDIAN	TRMEAN	STDEV	SEMEAN	MIN	MAX
$\ln(C^{SA})$	15	8.8505	8.8348	8.8490	0.0421	0.0109	8.7926	8.9285

ACF of $\ln(C^{SA})$

```
             -1.0 -0.8 -0.6 -0.4 -0.2  0.0  0.2  0.4  0.6  0.8  1.0
               +----+----+----+----+----+----+----+----+----+----+
     1   0.510                          XXXXXXXXXXXXXX
     2  -0.070                        XXX
     3  -0.266                   XXXXXXXX
     4  -0.260                    XXXXXXX
     5  -0.309                  XXXXXXXXX
     6  -0.280                   XXXXXXXX
     7  -0.148                      XXXXX
     8  -0.157                      XXXXX
     9   0.023                          XX
    10   0.299                          XXXXXXXX
    11   0.316                          XXXXXXXXX
    12   0.042                          XX
    13  -0.131                       XXXX
    14  -0.068                        XXX
```

autocorrelation and some ninth to tenth year lagged negative autocorrelation. For the period 1975 to 1989, the data shows first lag positive autocorrelation and some four to five year cycle of autocorrelation swinging from negative to positive.

B.4 Summary of Autocorrelation Analysis

The autocorrelation analysis points out three significant results which include:

1) The data sets of 1960 to 1974 and 1975 to 1989 are indeed quite different. This provides further support for separating the data when conducting the regression analysis.

2) During 1960 to 1974, all data show strong first lag positive autocorrelation and some nine to ten year lag negative autocorrelation. This suggest that there is some long-term cycle affecting the growth of consumption of these three chemicals.

3) During 1975 to 1989, all data show first year lag positive autocorrelation with some four year lag negative autocorrelation, followed by roughly eight year lag positive autocorrelation. This suggests that there is still some cycle affecting the consumption growth of these chemicals but that this cycle has now become shorter.

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