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TIME-VARYING RATIOS OF PRIMARY AND SCRAP METAL PRICES: THE IMPORTANCE OF INVENTORIES

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Abstract Although metal markets are subject to short run disequilibria and metal prices follow an adjustment mechanism over time, the links between primary and scrap metal prices have been assumed constant. This study explores potential primary and scrap price relationships using time series methodology applied to aluminum, copper, lead, and zinc prices for the period 1984-2000. The results show that even though a long run equilibrium between primary and scrap prices exists, persistent short run dynamics lead to unstable relationships in the short run. The short run relationships between primary and scrap prices, expressed through the ratios of primary and scrap prices, are stronger in some periods than others. A model which relates the ratio of primary and scrap prices to levels of primary metal stocks is proposed and evaluated. The model shows that inventories are positively related to the ratios of primary to scrap prices and provides a key to understanding the adjustment mechanisms between scrap and primary prices.

Time-Varying Ratios of Primary and Scrap Metal Prices: The Importance of Inventories

I. Introduction

Recycled materials act both as inputs into the production of and as substitutes for refined primary materials. As a consequence, fluctuations in demand and supply in the recycled material markets both influence and are influenced by the primary material markets. These links are evident in terms of prices which express the market information available at every point in time.

In the seventies and eighties, many studies examined links between primary and scrap metal fundamentals, including prices, through structural modeling. Fisher and Owen (1981) expressed explicit structural relationships for scrap and primary aluminium and indicated a connection between primary and scrap prices. Employing a traditional structural analysis, Hashimoto (1983) argued that steel price fluctuations and co-movements of primary and scrap steel prices are due to the industry's inherent inelasticities and its sensitivity to the business cycle. Stollery (1983) modeled the demand and supply relationships between scrap, primary input, and primary output for copper and steel. His empirical model of copper showed that the scrap price varies in direct proportion to the primary London Metal Exchange (LME) price.

Although some studies found intertemporal linkages between primary and scrap prices, they assumed that the relationship was stable. The majority of studies examining primary and scrap price links have been based on the concept of rapid market clearing. To the contrary, metal markets are known to be inelastic in the short run and to follow flow and stock adjustment processes towards equilibrium. As a consequence, disequilibrium between primary and scrap prices has, to a great extent, been overlooked in the literature. It has been acknowledged only in Stollery's (1983) and Taylor's (1979) studies of the difference between primary and scrap copper prices – mostly as an investigation of the refiner's margin – and in the annual studies of copper recycling from USGS[1] which also include an examination of the difference between primary and scrap copper prices.

Understanding the changing character of primary and scrap price links is very important, not only for those involved in the recycling sector but for those involved with the primary metal market since greater than 50 percent of the industry's supply comes from recycling (USGS, 2000). This study revives the interest in primary and scrap market links and shows, through time series methods, that the relationship between primary and scrap prices is not constant over time but dependent upon market forces.

The study shows that primary and scrap prices hold a long run equilibrium relationship, but that their short run interaction is unstable. This information should be invaluable to metal products manufacturers as well as to dealers in scrap metal because their optimal long run and short run choices are often different. The changing relationship of the spread between primary and scrap prices is described in terms of their price ratios. Price ratios reflect both equilibrium and disequilibrium adjustments and are closely related to price differences[2] which have provided the only reference to short run disequilibrium between primary and scrap prices in past studies. Price ratios vary over time but the price ratio series are mean-reverting in many cases. The mean reversion of primary to scrap price ratios is important for scrap metal markets since it implies that policies which try to promote recycling through price manipulations may be able to decrease the spread between primary and scrap prices in the short term but may not lead to sustainable results.

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[1] Multiple years.
[2] For example $PS - aPP = 0$ is identical to $PS/PP = a$.

In addition, the analysis demonstrates that price ratio fluctuations are related to market conditions and to the physical availability of metal in the market as reflected in inventory levels. Thus, increasing the role of scrap in metal markets through technological improvements and higher market integration could have a stronger impact on scrap demand and supply than price-based policies. The theoretical explanation for the relationship between price ratios and inventories is provided by the production-smoothing incentives of metal producers which lead to tighter connections between primary and scrap prices when inventories are lower than when inventories are higher. In a tight market, the spread between primary and scrap prices becomes smaller. When supply is ample, as indicated by high inventory accumulation, the spread between primary and scrap prices becomes wider. Establishment of this relationship provides market participants with valuable insight into the relative behaviour of the primary and scrap metal sectors by allowing them to anticipate and forecast primary to scrap price spreads.

II. Primary and Scrap Price Behavior

II. a. Primary and Scrap Prices

Four metal markets are analyzed – aluminium, copper, lead, and zinc – utilizing United States average monthly prices for the period of 1984-2000[3]. Primary prices represent values for refined metal which can be produced either from primary ore/concentrate or scrap metal. The primary prices used are the producer price of primary aluminum (PPA), the producer price of delivered copper cathode (PPC), the New York delivery prices of the primary producers' pig lead (PPL), and the domestic and foreign producer prices for primary zinc slab delivered in the United States (PPZ)[4].

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[3] The case of aluminum is studied for the period of 1985-2000, and the case of zinc for the period 1984-1996.
[4] PPA and PPC were obtained from the United States Geological Survey specialists P. Plunkert and D.L Edelstein respectively. PPL is published in the Commodity Research Bureau Commodity Yearbook, and PPZ is available in

Commercial scrap metal can be divided into new and old scrap. New scrap, such as cuttings and turnings, is generated during processing and fabrication of metal products and is usually denoted as No.1 scrap. It is desirable for its higher quality and for its consistency in terms of content and supply. New scrap prices included in the study are for aluminum clippings (PS1A), for brass mills No. 1 copper scrap (PS1C), and for new zinc clippings (PSZ). Old scrap, usually labelled No. 2 scrap, is metal incorporated in post-consumer products, obsolete manufactured products, or spent materials. Old scrap prices in the study are for old sheet and cast aluminum (PS2A), the producer price for aluminum used beverage can scrap (PS3A), the price for refiners' No.2 copper scrap (PS2C), and the smelters' buying price for heavy soft scrap lead (PSL)[5].

The primary and scrap prices in each market are presented in figure 1 while table 1 shows their time series characteristics including Phillips and Perron [P-P] (1988) unit root tests that indicate that the price series are integrated of order one, i.e. I(1). Appendix A provides an explanation of the relationship between primary and scrap prices by averaging their mean and volatility over three-year periods. Primary and scrap prices move in the same direction but are not always in correspondence.The degree of variation is higher for scrap prices in terms of coefficients of variation with the exception of aluminium cans and new scrap copper. Primary and scrap prices are interrelated. However, in contrast to past studies which assume instantaneous and simultaneous reactions, this description indicates that the links between primary and secondary prices are not constant over time. The differing degree of price variation

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the Metal Statistics publication of the American Metal Market. The length of each time series is determined by data availability and compatibility.

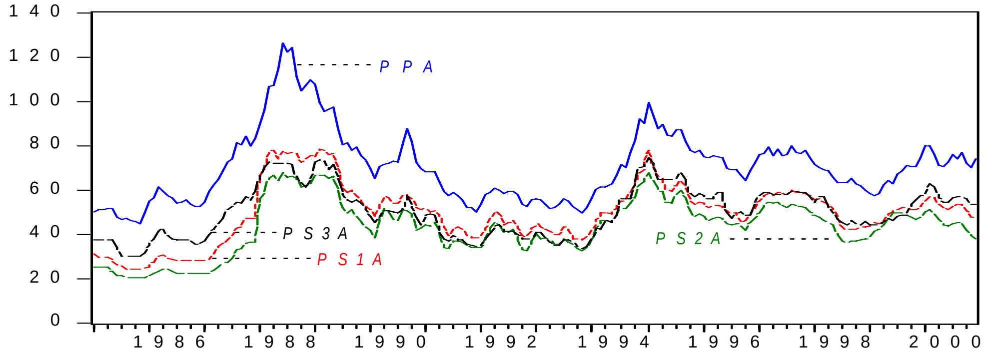
[5] The Metal Statistics publication of the American Metal Market is the source for PS1A, PS2A, PSL, and PSZ. We obtained PS1C and PS2C from the United States Geological Survey specialist D.L. Edelstein, and PS3A from the Commodity Research Bureau Commodity Yearbook. The length of each time series is determined by data availability and compatibility.

for primary and scrap metals is an indication that the short-term primary and secondary price changes are not always synchronous. Both primary and secondary markets adjust to exogenous and endogenous changes with time lags and can be subject to disequilibrium conditions in their own market or in relation to each other, at least in the short term. As can be seen in figure 2, the price ratios of primary and secondary metals show that the relationship between primary and scrap prices is not constant over time.

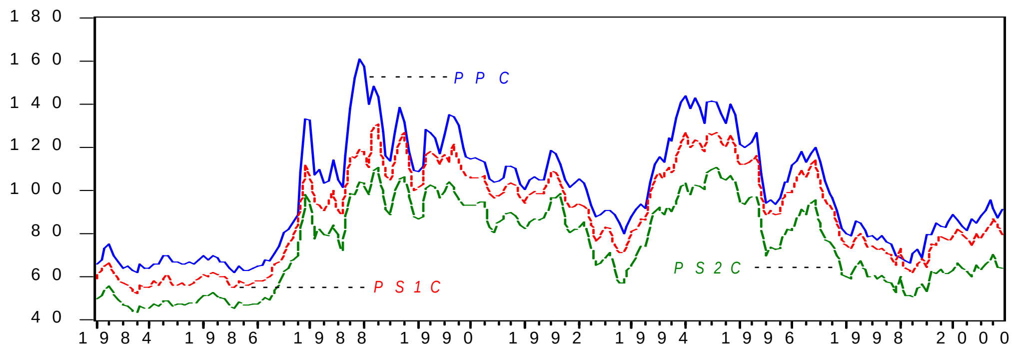
Table 1. Characteristics of Primary and Scrap Prices by Metal

Characteristic	Price Series										
	Aluminum				**Copper**			**Lead**		**Zinc**	
	PPA	PS1A	PS2A	PS3A	PPC	PS1C	PS2C	PPL	PSL	PPZ	PSZ
Mean	70.66	49.74	43.45	50.30	98.43	88.80	75.02	37.96	15.61	53.58	31.30
Standard Deviation	16.16	13.29	12.36	11.38	24.86	22.00	19.73	9.24	4.86	13.45	10.44
Coef. of Variation	0.229	0.267	0.284	0.226	0.253	0.248	0.263	0.243	0.312	0.251	0.334
Skewness	1.005	0.161	-0.056	0.260	0.284	0.003	0.019	-0.519	-0.159	0.997	0.277
Kurtosis	4.116	2.759	2.456	2.196	2.089	1.783	1.665	2.306	2.534	3.477	2.680
Jarque-Bera (J-B)	42.26	1.29	2.47	7.34	9.80	12.60	15.16	13.24	2.70	27.32	2.66
Probability (J-B)	0.000	0.524	0.291	0.025	0.007	0.002	0.001	0.001	0.259	0.000	0.264
P-P Unit Root Test											
Levels	-2.262	-2.220	-2.244	-2.244	-2.251	-2.063	-2.081	-1.614	-2.017	-1.888	-1.939
Probability*	0.186	0.200	0.192	0.192	0.189	0.260	0.253	0.474	0.280	0.337	0.314
First Differences	-10.55	-10.17	-9.84	-9.21	-10.56	-12.08	-11.90	-10.86	-11.60	-7.50	-10.07
Probability*	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1% Critical Value	-3.465	-3.465	-3.465	-3.465	-3.462	-3.462	-3.462	-3.462	-3.462	-3.473	-3.473
5% Critical Value	-2.877	-2.877	-2.877	-2.877	-2.876	-2.876	-2.876	-2.876	-2.876	-2.880	-2.880

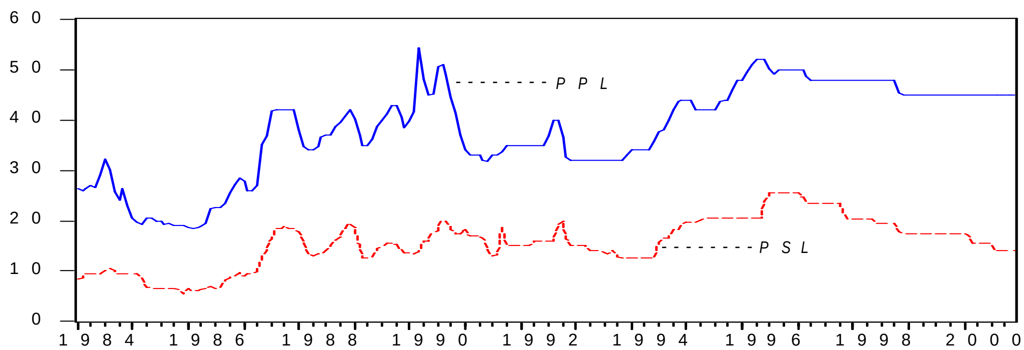
*MacKinnon (1996) one-sided p-values for rejection of hypothesis of a unit root



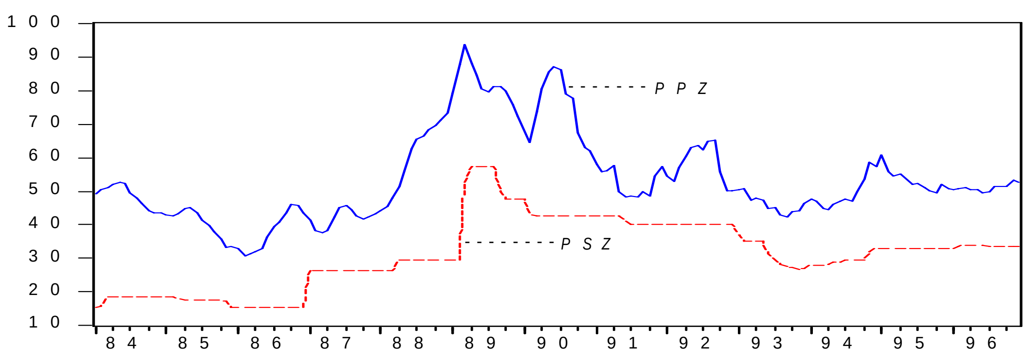
Aluminum (1985-2000)



Copper (1984-2000)

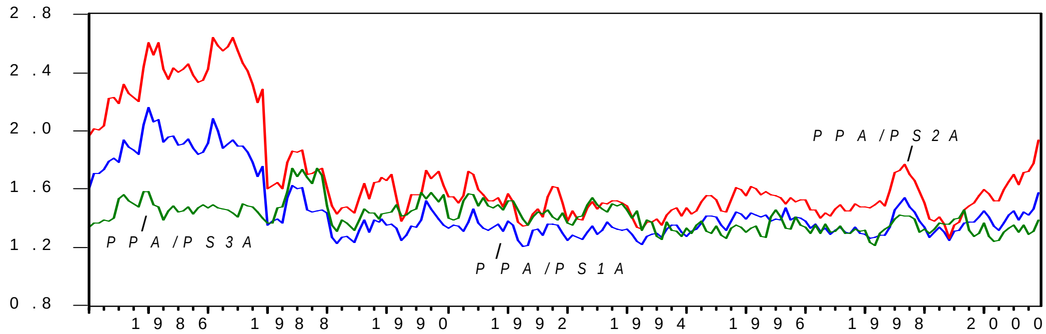


Lead (1984-2000)

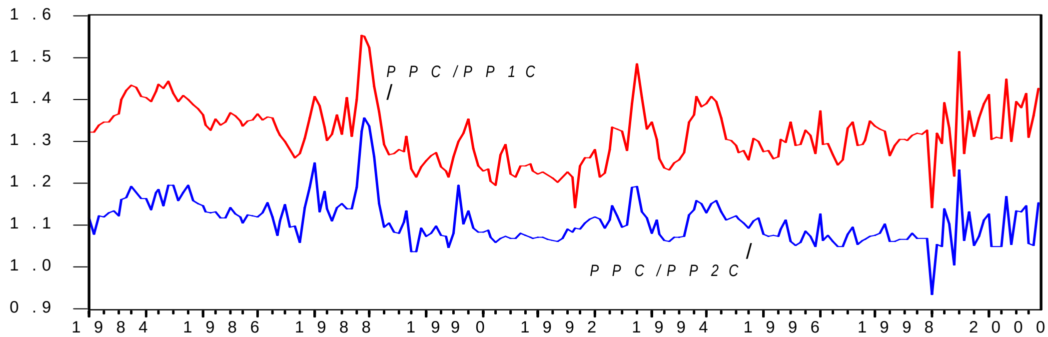


Zinc (1984-2000)

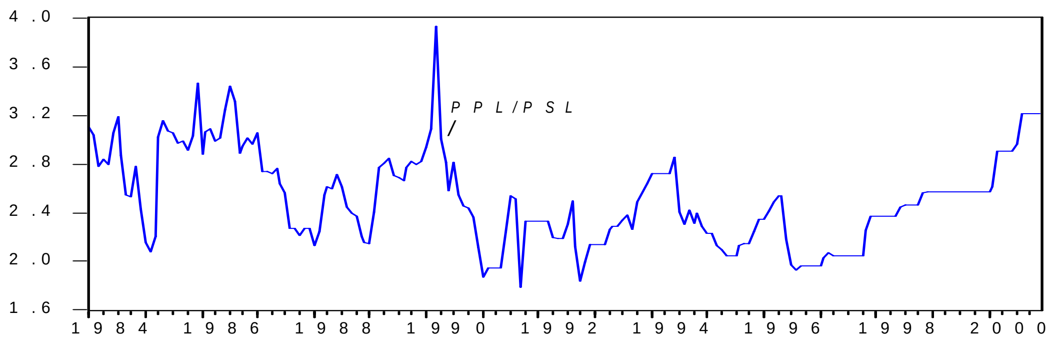
Figure 1. Primary and Scrap Price Series by Metal



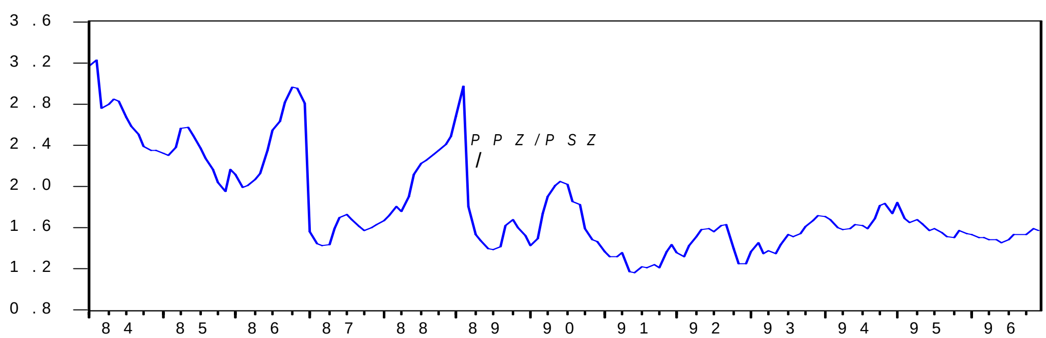
Aluminum (1985-2000)



Copper (1984-2000)



Lead (1984-2000)



Zinc (1984-1996)

Figure 2. Primary and Scrap Price Ratios by Metal

II. b. Primary and Secondary Price Relationships

On average, one would expect the spread between the primary price and the scrap price to simply reflect the refinery margin. In the short run, however, changes in the primary prices may not completely explain changes in the scrap prices because constraints do not always allow market clearing (Taylor, 1979). Cointegration analysis has established that variables may have an equilibrium relationship in the long run as explained by economic theory even though disequilibria in the short term are possible. Specifically, Engle and Granger (1987) point out that a linear combination of two or more non-stationary series may be stationary. If such a stationary linear combination exists, the non-stationary time series are said to be cointegrated. The stationary linear combination is called the cointegrating equation and is interpreted as a long-run equilibrium relationship between the variables. If two variables are cointegrated, they cannot move too far away from each other. In contrast, a lack of cointegration suggests that such variables have no long run link and can wander arbitrarily far away from each other.

Since the primary and scrap prices in each market are non-stationary of order one [I(1)] (table 1), cointegration testing allows for the establishment of a long run equilibrium relationship between primary and scrap prices even though short run price dynamics may reflect disequilibrium. The Johansen (1991, 1995) cointegration tests reveal not only the long run relationship but also short run dynamic information based on the Vector Error Correction (VECM) models that are produced.

Johansen's method tests the restrictions imposed by cointegration on the unrestricted Vector Autoregression (VAR) model involving k series. For primary and scrap prices the unrestricted VAR is

$$P_t = A_1 P_{t-1} + \ldots + A_p P_{t-p} + \varepsilon_t \, ,$$

where P_t is a vector including one primary and one scrap price series (both non-stationary I(1) variables), and ε_t is a vector of innovations. The VAR is transformed in the following VECM:

$$\Delta P_t = \Pi P_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta P_{t-i} + \varepsilon_t, \qquad \text{where } \Pi = \sum_{i=1}^{p} A_i - I_i, \quad \Gamma_i = -\sum_{j=i+1}^{p} A_j$$

Granger's representation theorem (Johansen, 1991; Engle and Granger, 1987) asserts that if the coefficient matrix Π has reduced rank r < 2 for the bivariate case, then there exist 2 × r matrices α and β each with rank r such that $\Pi = \alpha\beta'$ and $\beta' P_{t-1}$ is stationary. In the bivariate case there can be at most one independent combination of the variables in P_t ($\beta' P_{t-1}$) that is stationary. The variable, r, is the number of cointegrating relations; in the bivariate case the cointegrating rank cannot be larger than one. Each column of β is the cointegrating vector (characterizing the long run relationship between the primary and scrap price), and the elements of α are known as the adjustment parameters of primary and scrap prices to their cointegrating (long run) relationship.

The cointegrating term is also known as the error correction term since the deviation from long run equilibrium between primary and scrap prices is corrected gradually through a series of short run price adjustments towards this equilibrium. The adjustment rates measure the speed of adjustment of the short run changes of prices to their long-run relationship and show the persistence of short run disequilibrium conditions.

The cointegration analysis[6] is presented in table 2. The first five columns show the cointegration test results. The sixth column shows the long run relationship between the primary and scrap price for each pair. The last two columns show the adjustment rates of the price changes to their cointegrating relationship. Primary prices are found to hold a long run

[6] Eviews (version 5.1) was used for parameter estimation.

relationship to scrap prices with the exception of old and new aluminum prices. The primary products of old and new scrap aluminum, cast aluminum products, are sold in markets that are separate from those of primary aluminum and, as a consequence, it is not inconsistent that these scrap prices are not found to have a long run relationship to primary aluminum prices.

Table 2. Evidence of Cointegration between Primary and Scrap Prices by Metal

Prices	Ho: r=p	Max. Eigenvalue Test		Trace Test		Cointegrating	Adjustment Rates (α)	
		Statistic	Prob.^^	Statistic	Prob.^^	Relationship ($\beta' P_{t-1}$)	Primary Price	Scrap Price
Aluminum								
PPA,PS1A	p=0	10.28	0.310	16.99	0.133			
	p≤1	6.71	0.142	6.71	0.142			
PPA,PS2A	p=0	6.66	0.711	11.47	0.498			
	p≤ 1	4.81	0.305	4.81	0.305			
PPA,PS3A	p=0	15.35^	0.009	15.38^	0.015	PPA_{t-1} - 1.41$PS3A_{t-1}$	-0.06	0.06
	p≤ 1	0.03	0.892	0.03	0.892	(-51.43)***	(-1.39)	(1.89)*
Copper								
PPC,PS1C	p=0	28.33^	0.000	28.36^	0.000	$PS1C_{t-1}$ -0.9PPC_{t-1}	0.16	-0.16
	p≤ 1	0.04	0.871	0.04	0.871	(-124.18)***	(1.49)	(-1.84)*
PPC,PS2C		26.63^	0.001	30.73^	0.001	$PS2C_{t-1}$ -0.82PPC_{t-1}+5.66	0.15	-0.14
		4.1	0.398	4.1	0.398	(-26.77)*** (1.83)*	(1.37)	(-1.76)*
Lead								
PPL,PSL	p=0	26.13^	0.005	32.10^	0.007	PSL_{t-1} -0.65*PPL_{t-1}+0.03t+5.4	-0.01	-0.14
	p≤ 1	5.96	0.465	5.96	0.465	(-7.99)*** (2.23)**	(-0.11)	(-5.02)***
Zinc								
PPZ,PSZ	p=0	18.09^	0.022	20.87^	0.041	PPZ_{t-1}-1.24*PSZ_{t-1}-13.86	-0.02	0.08
	p≤ 1	2.78	0.622	2.78	0.622	(-6.28)*** (-2.14)**	(-0.87)	(4.15)***

^denotes rejection of the hypothesis at the 0.05 level
^^MacKinnon-Haug-Michelis (1999) p-values
t-statistics in parentheses. Asterisks indicate significance at *--0.10, **--0..05, ***--0.01 level.

In relation to the short run disequilibrium between primary and scrap prices, results show that the adjustment rates of primary and scrap prices to their cointegrating relationship are not high[7]. This suggests that short run disequilibrium movements can be persistent and denotes the importance of understanding the short-term relationships between primary and scrap prices. In addition, adjustment rates are statistically significant only for scrap prices. This means that most of the adjustment towards the long run relationship between primary and scrap prices is borne by adjustments in the scrap market.

III. Primary to Scrap Price Ratios

To examine the time-varying spread between primary and secondary prices, the analysis relies on price ratios. Cointegration analysis separates the disequilibrium dynamics from the equilibrium adjustments of the primary and scrap prices. By using price ratios it is possible to include both disequilibrium and equilibrium adjustments that occur between primary and scrap prices. The close relationship between price ratios and price differentials provides the connection of the vector error correction models of the primary and scrap prices analyzed above to their price ratios. As Granger indicated in his 2003 Nobel Prize Lecture, "a potentially useful property of forecasts based on cointegration is that when extended some way ahead, the forecasts of the two series will form a constant ratio" (Granger, 2004: p. 362).

The secondary/primary price ratio indicates the relative attractiveness of choosing secondary versus primary inputs in the production process and is an explanatory factor for recycling rates (Van Beukering and Bouman, 2001). Price ratios are also important for secondary smelters and refineries (producing primary metal mainly from scrap) since their profitability and survival depends on the price margin between scrap and the refined primary output. In this

[7] The speed of adjustment can range from zero to one.

context, Taylor (1979) used the relative scrap to primary price ratio in explaining primary prices. The time varying relationship between primary and scrap prices was analysed by Fowler (1937), who took an interest in iron ore and steel scrap price ratios relative to their consumption ratios for producing steel and found that there were differences in the elasticity of substitution between different periods.

The primary to scrap price ratios are presented in figure 2. Appendix A includes a summary of the price ratios data by averaging over three-year periods. Table 3 shows their time series characteristics, including Phillips and Perron (1988) unit root tests. The following conclusions can be drawn for primary to scrap price ratios:

(i). The means of the price ratios are not consistent over the twenty-year period. In some periods scrap prices are closer, indicating a stronger relationship to the primary metal prices relative to other periods.

(ii). The price ratios are stationary in many cases and the evidence favors a constant mean. This supports the finding already indicated through cointegration analysis that the primary and scrap prices tend to revert to a long run relationship.

(iii). The temporal patterns of price ratio means and volatility differ between markets. In addition, the temporal patterns of the price ratios within each market are similar for different types of scrap. This would suggest that a market specific explanation of the price ratio behaviour is indicated.

Table 3. Characteristics of Primary to Scrap Price Ratios by Metal

Characteristic	Price Ratio Series						
	Aluminum			**Copper**		**Lead**	**Zinc**
	PPA / PS1A	PPA / PS2A	PPA / PS3A	PPC / PS1C	PPC / PS2C	PPL / PSL	PPZ / PSZ
Mean	1.456	1.692	1.411	1.11	1.319	2.517	1.821
Standard Deviation	0.223	0.35	0.1	0.053	0.071	0.381	0.477
Coef. of Variation	0.153	0.207	0.071	0.048	0.054	0.151	0.262
Skewness	1.46	1.431	0.824	1.313	0.463	0.487	1.046
Kurtosis	3.905	3.77	4.013	7.304	3.523	2.965	3.154
Jarque-Bera (J-B)	74.743	70.283	29.919	216.126	9.603	8.069	28.626
Probability (J-B)	0.000	0.000	0.000	0.000	0.008	0.018	0.000
P-P Unit Root Test							
Levels	-1.853	-1.783	-4.086	-6.623	-5.839	-3.410	-1.468
Probability*	0.354	0.388	0.001	0.000	0.000	0.012	0.133
First Differences	-14.75	-13.50	-	-	-	-	-10.17
Probability*	0.000	0.000	-	-	-	-	0.000
1% Critical Value	-3.465	-3.465	-3.465	-3.462	-3.462	-3.462	-2.58
5% Critical Value	-2.877	-2.877	-2.877	-2.876	-2.876	-2.876	-1.943

*MacKinnon (1996) one-sided p-values for rejection of hypothesis of a unit root

III. a. Inventory Influences

Market fundamentals allow an understanding of the behaviour of primary to scrap price ratios. Low price ratios seeming to reflect tight supply/demand balances (low stock levels) suggest that market fundamentals do influence the spread between primary and scrap prices. The graphs and time series characteristics of the inventory series (in logarithmic form) for the period 1984-2000 are presented in figure 3 and table 4 respectively[8]. Periods of low price ratios coincided with periods of low market inventories. For aluminium, the price ratio was low during 1988, 1990, 1993, 1996-1997, and 1999-2000, all periods of low inventories. For lead, low price

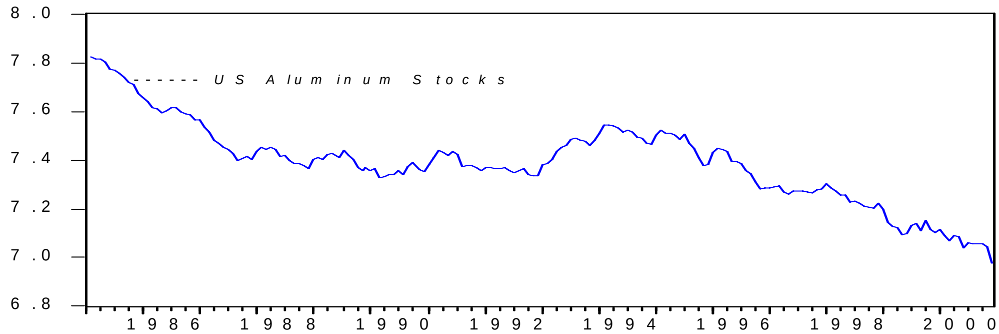
[8] The inventories used are United States stocks at the end of each month. Aluminum stock data was available only for North America. The source for the North American Aluminium stocks, denoted in the paper, as USAS, is the International Aluminum Institute. The Copper stocks (USCS) where estimated from segregated US copper stocks compiled by the United States Geological Survey specialist, D.L. Edelstein. The Metal Statistics publication of the American Metal Markets provided the source for lead (USLS) and zinc (USZS) stocks. The length of each time series is determined by data availability and compatibility.

ratios were experienced in the low inventory periods of 1984-1985, 1988, 1991. In contrast, the periods of 1985-1986, 1986-1987, and 1995-96 had high inventory accumulation with high lead price ratios. Examination of the effect of supply influences on the spread between primary and scrap prices brings to light that short zinc supply in 1987-1989 was accompanied by low price ratios while worldwide supply shortages of aluminium in 1986-1988 coincided with high price ratios. The reason for this inconsistency in the relation of price ratios to supply is that supply shortages for aluminium during 1986-1988 where buffered by drawing from the industry's high inventories. Shortages for zinc in 1987-1989, however, coincided with low zinc inventories. Furthermore, it is noted that reduced demand in 2000 was accompanied by increased ratios, except in the case of aluminium, where the period was characterised by a reduction in inventories and the price ratios were low.

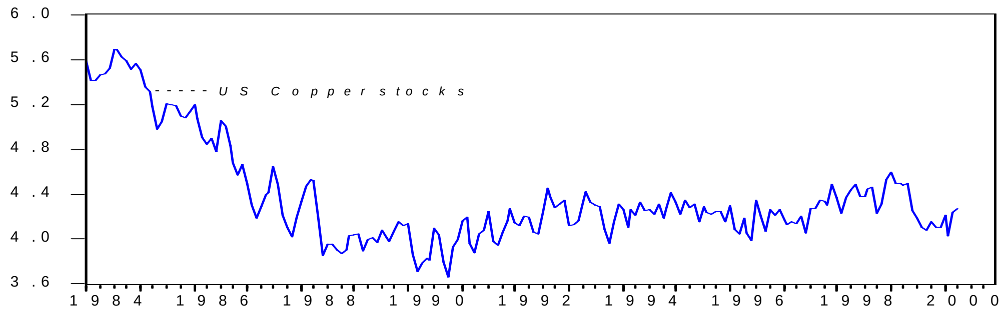
Table 4. Characteristics of US Metal Stocks

Characteristic	Inventory Series			
	lnUSAS	**lnUSCS**	**lnUSLS**	**lnUSZS**
Mean	7.390	4.377	3.360	9.165
Standard Deviation	0.167	0.449	0.795	0.693
Coef. of Variation	0.023	0.102	0.237	0.076
Skewness	0.059	1.391	-0.017	1.250
Kurtosis	3.356	4.211	2.035	3.168
Jarque-Bera (J-B)	1.117	75.151	7.929	40.782
Probability (J-B)	0.572	0.000	0.019	0.000
Phillips-Perron Unit Root Test				
Levels	-1.666	-2.916	-2.641	-1.828
Probability*	0.763	0.045	0.087	0.366
First Difereences	-11.19	-	-	-11.98
Probability*	0.000	-	-	0.000
1% Critical Value	-4.007	-3.464	-3.462	-3.473
5% Critical Value	-3.434	-2.876	-2.876	-2.880

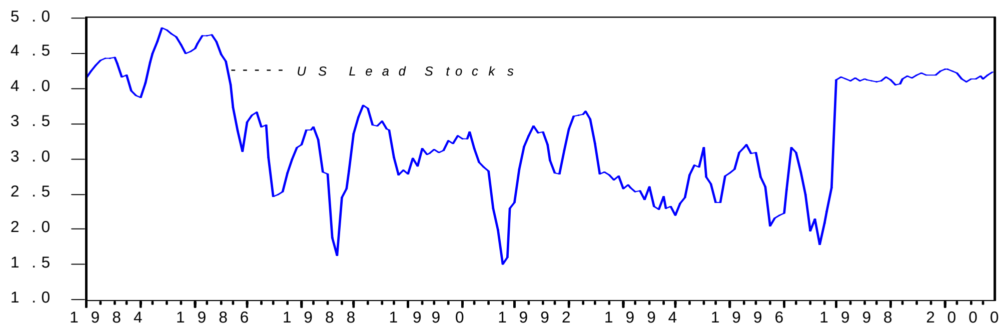
*MacKinnon (1996) one-sided p-values for rejection of hypothesis of a unit root



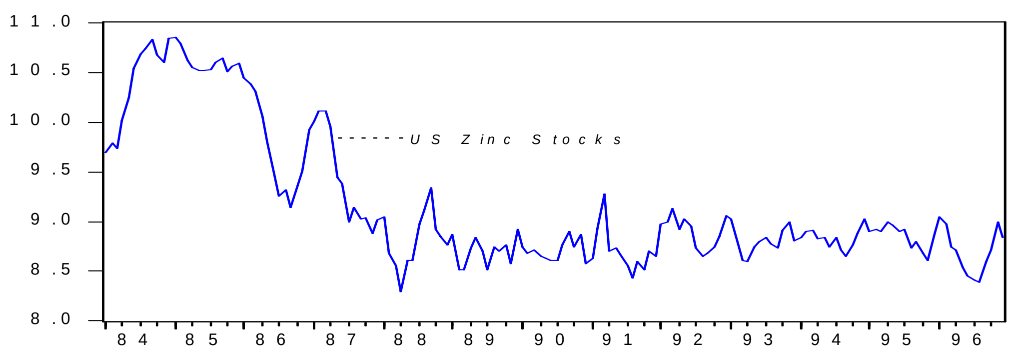
Aluminum (1985-2000)



Copper (1984-2000)



Lead (1984-2000)



Zinc (1984-1996)

Figure 3. Metal Stocks (in logarithmic form)

It appears that the major determinant of price ratios is the tightness in the market, represented by inventory availability. Scatter plots of price ratios to United State inventories presented in figures 4-7 attest to a positive relationship between price ratios and inventories. The plots also include a line of fit to improve interpretation of the relationship that connects them.

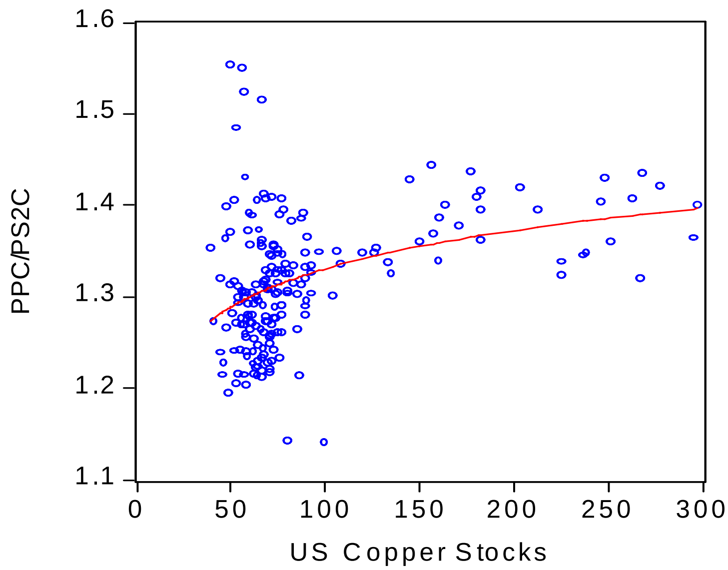


Figure 4. Scatter Plot of the Price Ratio of Primary to Old Scrap Copper (PPC/PS2C) to Copper Inventories

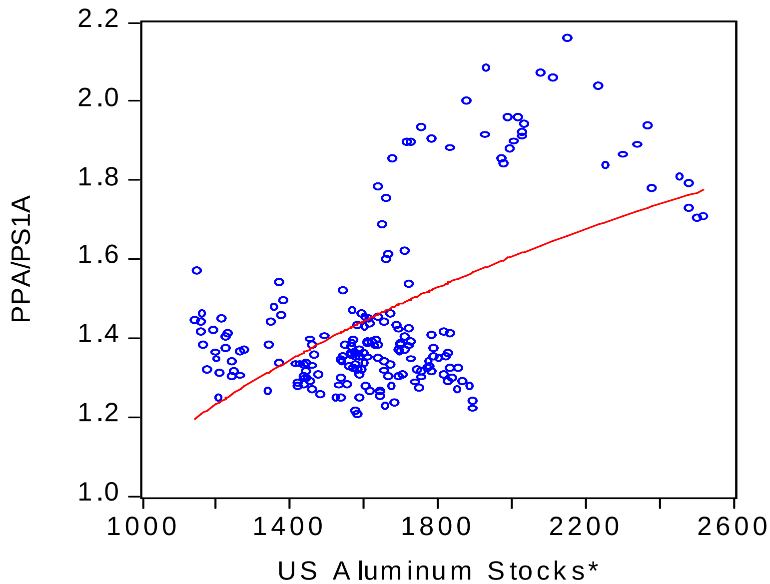


Figure 5. Scatter Plot of the Price Ratio of Primary to New Scrap Aluminum (PPA/PS1A) to Aluminum Inventories*

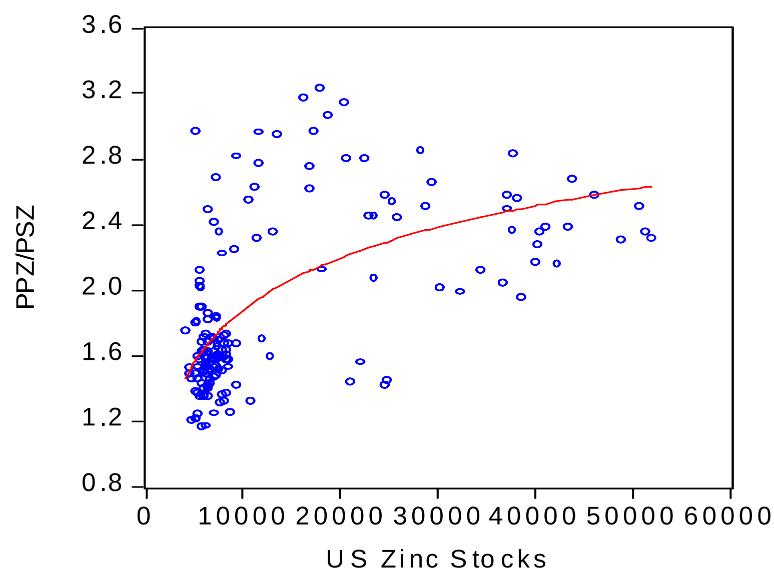


Figure 6. Scatter Plot of the Price Ratio of Primary to New Scrap Zinc (PPZ/PSZ) to Zinc Inventories

* lagged by one month.

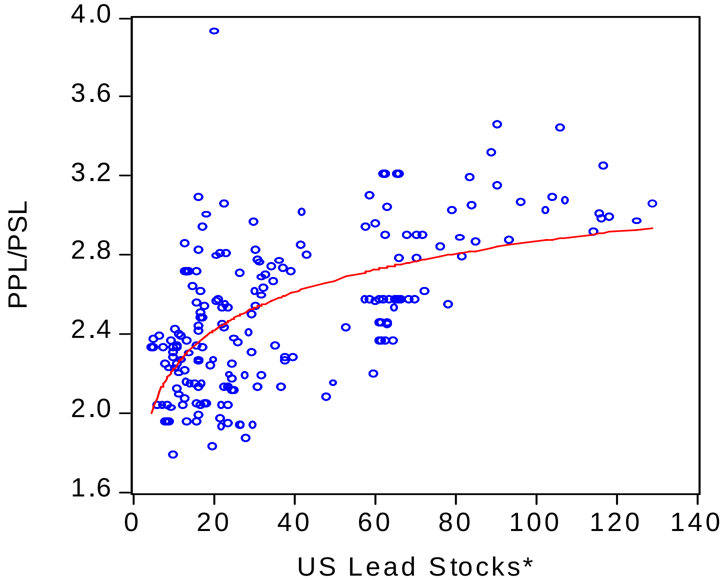


Figure 7. Scatter Plot of the Price Ratio of Primary to Old Scrap Lead (PPL/PSL) to Lead Inventories*

IV. Modeling Price Ratios

IV. a. Nature of Inventories

Stocks are a major factor in metal markets. They provide the intertemporal link in dynamic commodity systems and form the basis of price adjustment since demand and supply are inelastic (Labys and Kaboudan, 1980). Primary and scrap metal demand and supply do not always clear (*D*=*S*) in the short-term due to technological, institutional and psychological constraints. The discrepancy between supply and demand is then carried over to the subsequent period through inventory changes. When the market is in a period of excess supply, in which metal production exceeds metal demand, the excess is added to the accumulated stocks. When demand exceeds supply, stocks are drawn down to cover the excess demand. Current inventories are defined as the summation of supply and demand changes as well as inventory accumulation carried over from the past periods:

* lagged by one month.

$$I_{p,t} = I_{p,t\text{-}1} + S_{p,t} - D_{p,t} \quad (1)$$

Thus, inventories express market conditions, both as current flow changes and as past accumulation of stocks. Consequently, they can allow inferences about how market conditions influence primary and secondary prices.

The role of inventories emphasizes the dynamic character of metal markets and indicates the disequilibrium forces that are embodied in the market. It would be expected that the disequilibrium between primary and scrap prices be related to a variable (such as inventories) that embodies disequilibrium conditions. In addition, stocks are a determinant of both primary and scrap prices.

When demand and supply are inelastic, as is the case in metal markets, a stock adjustment process determines primary metal price behaviour. Taylor (1979) introduced the influence of stocks on scrap prices as well in his short run model of the copper industry. Since both primary and scrap prices are explained by inventories, the ratio of primary to scrap prices should also be influenced by inventories. This is especially obvious if it is taken into account that the reactions of primary and scrap prices to market forces will be different and come with different adjustment rates.

IV. b. The Production Smoothing Model

Production smoothing is an explanation for the use of stocks in inelastic markets. It points out that adjusting production to changes of demand would be accompanied by high adjustment costs. This stems from the high investment cost in production expansion and the rigidity of electricity, primary input and labor contracts. In addition, it acknowledges that firms face convex production cost curves and fluctuating market demand. Under such conditions, firms have incentives to use inventories to buffer demand shocks and smooth production (Holt et al., 1960) or production costs (Eichenbaum, 1984, 1989).

In the presence of low demand, excess supply is stored as inventory in order to avoid production cuts and consequent adjustment cost; in periods of high demand, difficulties and increased costs resulting from higher production can be avoided by absorbing buffer stocks. Capacity is unlikely to be expanded or contracted in the short run; expansion (contraction) would occur only when clear (but often misleading) signals of long-term increasing (decreasing) prices unfold. Based on the incentives for production smoothing, low stocks, indicating high demand and short supply in the market, would also lead to the utilization of relatively more scrap than usual as a metal input or substitute. The cost of disrupting the flow of operations is linked to the use of primary ore and concentrate: scrap, which is a more flexible input than primary ore, can be used to smooth production and production costs.

In periods of excess demand, increased supply orders can easily be covered by scrap, and higher marginal costs from the use of primary ore can be avoided. The relative use of scrap directly from metal consumers, as a substitute for primary metal, also increases as the market tightens and the primary metal industry is not able to respond swiftly to demand. Thus, when inventories are low, the ratio of primary to secondary demand decreases, leading subsequently to a smaller primary to scrap price ratio. In contrast during low demand, when stocks are high, production and production cost-smoothing implies that relatively less scrap is used as input to primary production. Ore and concentrate are preferred to scrap in order to avoid the idling of production capacity. Although both primary and scrap demand are low when inventories are high, their demand ratio widens and so does the primary to scrap price ratio. The first hypothesis that arises from this analysis is that the ratio of primary to scrap metal prices is positively linked to inventories. However, technological, psychological, and institutional constraints in the market, as well as the influence of expectations, could mean that the ratio of primary to scrap prices adjusts to inventories over time. Therefore, it is expected that the positive relationship between the ratios of primary to secondary metal prices and inventories occurs with time lags.

IV. c. Time Series Models

Since metal markets are characterized by stock adjustments and expectation functions, the hypotheses are tested under a dynamic framework with autoregressive (ARMAX) models as described in equation 2. Current and past inventories as well as lagged price ratios incorporate information about the fundamentals of the market. The scatter plots in graphs 4-7 indicate that the relationship between price ratios and inventories is asymmetric. Higher stocks lead to higher ratios at a decreasing rate since the difference between the primary and scrap prices is constrained by their technological and market relations. To express this asymmetry, inventories are transformed into logarithms.

$$(Pp/Ps)_t = c + \phi_k \sum_{1}^{k} (Pp/Ps)_{t-k} + \gamma \ln I_t + \delta \ln I_{t-1} + \varepsilon_t \qquad (2)$$

The ARMAX models explain the movement of a variable through time in terms of its own past values as well as current and past values of other explanatory variables. Time and relationships through time are an explicit part of the formulation. The lagged values of the price ratios and inventories appear as a consequence of the theoretical basis of the model, which takes into account past market information and allows economic agents to respond not only to current values but to past values as well.

When price ratios and inventories are stationary, the number of lags is chosen based only on the goodness of fit. When the price ratios are stationary, but inventories contain a unit root [I(1)], as in the case of modeling the ratio of aluminum primary to used aluminum can prices, regression equations including only current inventories or only inventories lagged by one period are meaningless because the error term contains a trend component. Including current and past values allows the individual coefficients of $\log I_t, \log I_{t-1}$ to be written as coefficients of stationary variables which implies that a t-statistic is appropriate for testing the influence of $\log I_t, \log I_{t-1}$ individually on the price ratios (Sims, Stock and Watson, 1990). Specifically, the distributions of the estimated coefficients γ and δ each converges at a rate corresponding to $\sqrt{T}$ to a Gaussian distribution. An F test of the joint hypothesis that γ and δ are both zero has a non-stationary limiting distribution and cannot be conducted, but it is possible to test the hypothesis of γ=0 and δ=0 being asymptotically N (0,1) separately for each variable (Hamilton, 1994) .

When both price ratios and inventories are non-stationary [I(1)] it is necessary to check whether a long run relationship exists between them. If cointegration is present, a Vector Error Correction model is produced. This approach is followed for the primary to scrap zinc price ratio as well as the ratios of primary to new and old aluminum scrap prices. The model of the price ratios under this formulation is described by:

$$\Delta(Pp/Ps)_t = c + a[(Pp/Ps)_{t-1} + \beta \ln I_{t-1}] + \sum_1^k \phi_k \Delta(Pp/Ps)_{t-k} + \sum_1^k \gamma_k \Delta \ln I_{t-1} + \varepsilon_t \qquad (3)$$

In this model the relationship of inventories to price ratios is examined both in the long term and in the short term.

V. Empirical Results

The empirical results of the price ratio models are presented in Table 5[9]. The coefficients differ considerably between metal markets. The functions of all the price ratios have significant

[9] The tests for cointegration between primary/scrap price ratios and inventories for zinc and aluminum and their full Vector Error Correction models are presented in appendix B. All computations were performed with E-views (version 5.1)

autoregressive coefficients. For the price ratios that are non-stationary, the autoregressive coefficient is one. The significance of the autoregressive coefficients testifies to the dynamic adjustment behavior of the metal markets.

Table 5. Models of Primary to Scrap Price Ratios

$\Delta(PPA/PS1A)_t = -0.065[PPA/PS1A_{t-1} - 0.58 lnUSAS_{t-1} + 2.622] - 0.0007 + \varepsilon_t$ (-2.682)* (-2.235)° (-0.159) Adj.R^2=0.032, AIC=-2.67	(4.1)
$\Delta(PPA/PS2A)_t = -0.046[PPA/PS2A_{t-1} - 0.809 lnUSAS_{t-1} + 4.295] - 0.0003 + \varepsilon_t$ (-2.216)° (-1.730)^ (-0.059) Adj.R^2=0.020, AIC=-2.03	(4.2)
$PPA/PS3A_t = 0.316 + 0.819 PPA/PS3A_{t-1} - 0.307 lnUSAS_t + 0.455 lnUSAS_{t-1} + \varepsilon_t$ (0.339) (19.369)* (-1.682)^ (2.443)° Adj.R^2=0.710, AIC=-2.97	(4.3)
$PPC/PS1C_t = 1.052 + 0.541 PPC/PS1C_{t-1} + 0.179 PPC/PS1C_{t-2} - 0.013 lnUSCS_{t-1}$ (12.508)* (7.500)* (2.469)° (-0.635) $+ 0.027 lnUSCS_{t-2} + \varepsilon_t$ (1.274) Adj.R^2=0.466, AIC=-3.63	(4.4)
$PPC/PS1C_t = 1.109 + 0.497 PPC/PS1C_{t-1} + 0.234 PPC/PS1C_{t-2} + 0.048 lnUSCS_{t-3} + \varepsilon_t$ (11.977)* (7.718)* (2.935)° (2.286)° Adj.R^2=0.533, AIC=-3.20	(4.5)
$PPL/PSL_t = 2.049 + 0.841(PPC/PS1C)_{t-1} + 0.141(lnUSLS)_{t-1} + \varepsilon_t$ (11.044)* (21.569)* (2.286)° Adj.R^2=0.77, AIC=-0.58	(4.6)
$\Delta(PPZ/PSZ)_t = -0.135[PPZ/PSZ_{t-1} - 0.554 lnUSZS_{t-1} + 3.255] + 0.227\Delta(PPZ/PSZ)_{t-1}$ (-3.503)* (-5.250)* (3.352)* (2.829)* $+ 0.020\Delta(PPZ/PSZ)_{t-2} + 0.036\Delta(PPZ/PSZ)_{t-3} - 0.048\Delta(lnUSZS)_{t-1}$ (0.242) (0.428) (-0.624) $- 0.121\Delta(lnUSZS)_{t-2} - 0.126\Delta(lnUSZS)_{t-3} + \varepsilon_t$ (-1.558) (-1.640) Adj.R^2=0.105, AIC=-0.76	(4.7)

t-statistics in parentheses: ^ indicates significance at 0.10 level, ° indicates significance at 0.05 level, * indicates significance at 0.01 level.

The effect of inventories on the primary/secondary price ratios is positive. Even though present inventory levels have a negative effect on the ratio of primary to used aluminum can prices, past values of inventories have a positive effect which surpasses the effect exerted by current inventories. The influence of stocks to price ratios is weakest in the copper market and is significant only for the ratio of primary to old scrap prices. Considerable inventory influence on the price ratios comes from past lags. Thus, the ratio of primary to secondary data does adjust to the changing market conditions with time lags.

In the cases of zinc price ratios and aluminum primary to old and new scrap price ratios, inventories hold a positive long run relationship to price ratios. Short run changes in price ratios also hold a positive relationship to inventories for aluminum. In the case of zinc, price ratios are influenced positively by the lagged inventory levels but are negatively affected by short run inventory changes although the short run influence is not statistically significant. Last, short run dynamics in these markets can be persistent since the adjustment rates to the long run relationship that exists between the price ratios and inventories are not high[10].

The ratio of primary to scrap metal prices is not constant since market conditions influence primary and secondary metal prices to differing degrees. Price ratios increase as inventories increase and decrease when inventories decline. This positive relationship of the primary/scrap price ratio to metal market inventories suggests that scrap prices react more violently to market condition changes than primary prices do. In times of ample supply, both primary and scrap prices decrease, but the fall in scrap prices is greater. In periods of excess demand and tight supply both primary and scrap prices increase, with scrap price increases being relatively higher.

[10] The speed of adjustment can range from zero to one.

Secondary smelters and refineries depend fully on scrap for metal production and are greatly affected by this phenomenon. These producers may find themselves at a disadvantage in relation to primary smelters and refineries because their input costs are more volatile than their sales and they have to engage in a great deal of market speculation. This may be the reason for many suggestions in the copper industry to link scrap prices to LME copper prices (Blomberg and Hellmer, 2000; Labys et al., 1971).

Finally, to the extent that price reactions to surface stocks could represent price adjustments to reduced underground stocks, long term downward sloping trends of the primary and scrap price ratio would indicate resource exhaustion. This is a possible direction for future research which may be able to produce more conclusive results about resource exhaustion than the study of primary resource prices alone. It is important to note that the positive long run relationship found between price ratios and inventories for zinc and aluminium validates this approach.

VI. Conclusions

This study describes interrelations between primary and scrap markets in terms of price ratios. Understanding the relative behaviour of primary and scrap prices can be valuable to metal market participants, especially in the decision making process of managers of secondary smelters and refineries. In examining the dynamic relationship of primary and scrap metal prices through time series methods, the results show that a long run equilibrium ties primary to scrap prices. However, short run dynamics include movements away and adjustments towards equilibrium. This unstable short run relationship between primary and scrap prices is verified by the time-varying ratios of primary to scrap prices. The fact that primary and scrap prices hold a long run relationship in most markets suggests that policies that aim to increase recycling rates by decreasing the primary to scrap price ratio will not be able to sustain long term results. Such policies could have a more significant effect in the old and new aluminium scrap markets where a long run relationship between primary and scrap prices is not present. In addition, knowledge that a long run equilibrium relationship exists between primary and scrap prices should make scrap market participants cautious about their reaction to short run fluctuations of scrap prices.

In the latter part of the paper, it is shown that price ratios are related to market fundamentals. The level of inventories in the market influences price ratios positively. In the case of zinc, as well as the cases of new and old aluminum, this relationship is more pronounced in the long run than the short run. Moreover, considerable inventory influence on price ratios comes from past lags, since the ratio of primary to secondary prices adjusts to the changing market conditions. The dynamic adjustment of price ratios to market information is also established by the significant autoregressive coefficients of price ratios. These results can help metal market participants anticipate or forecast relative changes in primary and scrap prices.

The theoretical explanation of the positive relationship between primary and scrap price ratios to inventories found in this paper is provided by the production smoothing incentives of metal producers. These lead to tighter connections between primary and scrap prices when inventories are lower than when inventories are higher. In a tight market, the spread between primary and scrap prices becomes smaller, whereas ample supply, as indicated by high accumulation of inventories, means wider spreads between primary and scrap prices. Although the empirical results attest to this structure for aluminium, zinc, and lead, the evidence is weaker in the case of copper. Understanding the reasons why this relationship is not as pronounced in the case of copper could provide additional insights into the structural relations between primary and scrap prices. It should also be noted that production smoothing incentives are a short run phenomenon and the long run equilibrium between inventories and price ratios, found in the case of zinc and new and old aluminium scrap, could suggest there may be other forces that lead to this relationship as well.

Finally, the positive relationship between the price ratios and the level of metal inventories found in this study indicates that as inventories increase (decrease), both primary and secondary prices increase (decrease), but scrap price reactions to market conditions are more pronounced. The flexibility of scrap as an input to primary metal production is the reason the ratio of primary to secondary prices is expected to hold a positive relationship to inventory levels. It is important to note that the estimated Vector Error Correction models of primary and scrap prices show that the partial adjustment towards the long run relationship between primary and scrap prices is achieved through scrap price movements. This indicates both the higher flexibility of scrap prices and the stabilizing force of the scrap sector for the metal markets.

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Appendix A

Table A1. Primary and Scrap Prices and Volatility by Metal (1985-1999)

Series	Prices									
	Means					**Standard Deviations**				
	1985-87	**1988-90**	**1991-93**	**1994-96**	**1997-99**	**1985-87**	**1988-90**	**1991-93**	**1994-96**	**1997-99**
Aluminum										
PPA	58.99	90.67	56.77	76.14	69.45	11.67	17.76	4.86	10.62	6.72
PS1A	31.47	65.21	43.05	56.16	51.87	6.79	10.53	4.10	8.15	5.95
PS2A	24.98	55.80	37.87	51.25	46.82	4.68	9.39	3.88	7.33	5.92
PS3A	40.52	60.57	39.08	57.00	52.17	8.24	10.00	4.07	9.14	5.91
Copper										
PPC	71.81	124.88	102.77	119.47	87.16	13.87	15.74	10.09	18.38	16.30
PS1C	63.08	109.85	94.17	108.56	81.19	12.10	11.03	11.04	14.63	15.30
PS2C	53.00	94.41	82.09	91.36	66.50	11.18	9.70	11.25	13.19	13.09
Lead										
PPL	25.92	40.65	33.74	43.86	46.98	8.49	5.14	2.13	5.86	1.64
PSL	9.62	15.67	15.32	19.51	20.11	4.33	2.22	1.82	4.07	2.62
Zinc										
PPZ	40.10	72.27	52.44	51.21	-	4.63	12.57	6.61	3.60	-
PSZ	19.84	40.33	37.45	32.01	-	4.87	10.46	5.07	2.09	-

Table A2. Price Ratios by Metal for Selected Time Periods

Series	Price Ratios				
	1985-87	**1988-90**	**1991-93**	**1994-96**	**1997-99**
Aluminum					
PPA/PS1A	1.883	1.387	1.321	1.358	1.343
PPA/PS2A	2.363	1.623	1.504	1.488	1.493
PPA/PS3A	1.459	1.495	1.456	1.341	1.335
Copper					
PPC/PS1C	1.139	1.137	1.094	1.098	1.074
PPC/PS2C	1.360	1.323	1.260	1.307	1.314
Lead					
PPL/PSL	2.820	2.621	2.224	2.296	2.365
Zinc					
PPZ/PSZ	2.112	1.861	1.412	1.602	-

Appendix B

Table B1. VECM Models for Price Ratios and Inventories

$$\Delta(PPA/PS1A)_t = -\,0.065[PPA/PS1A_{t-1} - 0.580\ln USAS_{t-1} + 2.622] - 0.0007 + \varepsilon_t \qquad \text{(C.1)}$$

(-2.682)* (-2.235° (-0.159)

Adj.R^2=0.032, AIC=-2.67

$$\Delta(\ln USAS)_t = -\,0.022[PPA/PS1A_{t-1} - 0.533\ln USAS_{t-1} + 2.622] - 0.004 + \varepsilon_t \qquad \text{(C.2)}$$

(-3.029)* (-2.235)° (-3.232)*

Adj.R^2=0.041, AIC=-5.07

$$\Delta(PPA/PS2A)_t = -\,0.046[PPA/PS2A_{t-1} - 0.809\ln USAS_{t-1} + 4.295] - 0.0003 + \varepsilon_t \qquad \text{(C.3)}$$

(2.216)° (-1.730)$^{\wedge}$ (-0.059)

Adj.R^2=0.020, AIC=-2.03

$$\Delta(\ln USAS)_t = -\,0.012[PPA/PS2A_{t-1} - 0.809\ln USAS_{t-1} + 4.295] - 0.004 + \varepsilon_t \qquad \text{(C.4)}$$

(-2.714)* (-1.730)$^{\wedge}$ (-3.217)*

Adj.R^2=0.033, AIC=-2.06

$$\Delta(PPZ/PSZ)_t = -\,0.135[PPZ/PSZ_{t-1} - 0.554\ln USZS_{t-1} + 3.255]$$

(-3.503)* (-5.250)* (3.352)*

$$+\,0.227\Delta(PPZ/PSZ)_{t-1} + 0.020\Delta(PPZ/PSZ)_{t-2} + 0.036\Delta(PPZ/PSZ)_{t-3}$$

(2.829)* (0.242) (0.428)

$$-\,0.048\Delta(\ln USZS)_{t-1} - 0.121\Delta(\ln USZS)_{t-2} - 0.126\Delta(\ln USZS)_{t-3} + \varepsilon_t \qquad \text{(C.5)}$$

(-0.624) (-1.558) (-1.640)

Adj.R^2=0.105, AIC=-0.76

$$\Delta(\ln USZS)_t = 0.126\,[PPZ/PSZ_{t-1} - 0.554\ln USZS_{t-1} + 3.255]$$

(3.326)* (-5.250)* (3.352)*

$$-\,0.254\,\Delta(PPZ/PSZ)_{t-1} - 0.051\,\Delta(PPZ/PSZ)_{t-2} + 0.047\,\Delta(PPZ/PSZ)_{t-3}$$

(-3.217)* (-0.616) (0.565)

$$+\,0.031\,\Delta(\ln USZS)_{t-1} + 0.148\,\Delta(\ln USZS)_{t-2} - 0.203\,\Delta(\ln USZS)_{t-3} + \varepsilon_t \qquad \text{(C.6)}$$

(0.406) (1.934)$^{\wedge}$ (-2.698)*

Adj.R^2=0.150, AIC=-0.79

t-statistics in parentheses: $^{\wedge}$ indicates significance at 0.10 level, ° indicates significance at 0.05 level, * indicates significance at 0.01 level.

Table B2. Tests for Cointegration between Price Ratios and Inventories

Prices	Ho: r=p	Maximum Eigenvalue Test			Trace Test		
		Statistic	5% Crit.Val.	Prob.**	Statistic	5% Crit.Val.	Prob.**
Aluminum							
PPA/PS1A,	p=0	19.108*	14.265	0.008	19.843*	15.495	0.010
USAS	p≤1	0.735	3.841	0.391	0.735	3.841	0.391
PPA/PS2A,	p=0	15.234*	14.265	0.035	15.925*	15.495	0.043
USAS	p≤1	0.692	3.841	0.406	0.692	3.841	0.406
Zinc		22.500*	15.892	0.004	26.475*	20.262	0.006
PPZ/PSZ,	p=0	3.975	9.165	0.416	3.975	9.165	0.416
USZS	p≤1						

*denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values