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ECONOMICS

THREE FACTS ABOUT WORLD METAL PRICES

by

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University of Western Australia**

DISCUSSION PAPER 13.01

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Abstract

We argue that the workings of world metal markets can be characterised by three facts:

- *Fact One*: Global determinants of prices do not dominate market-specific ones.
- *Fact Two* (in its simplest form): The relative price of a metal is inversely proportional to its relative volume of production. If, for example, global iron ore production expands 10 percent faster than the average for all metals, then its price falls by 10 percent.
- *Fact Three*: Metal prices exhibit well-defined short-term cycles that tend to repeat themselves.

These are not yet canonical facts, with proportional pricing arguably the most controversial. This paper shows that the three facts are still promising leads to understanding the evolution of metal prices.

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TABLE OF CONTENTS

1. INTRODUCTION	1
2. GLOBAL SHOCKS DO NOT DOMINATE	5
2.1 The Data	5
2.2 Two Indexes of Prices	6
2.3 Global and Commodity-Specific Shocks	7
2.4 The Exchange-Rate Regime, Global Risk and Economic Importance	10
2.5 Summary	11
3. NUTTING’S LAW IS (POSSIBLY) NOT NUTS	11
3.1 Multi-Metal Matrix (MMM) Comparisons	12
3.2 A Simple Metals Pricing Model	14
3.3 Nutting’s Law	16
3.4 An Assessment	17
4. PRICES CYCLE	20
4.1 The Data	20
4.2 Properties of the Cycle	22
4.3 A Moments Approach	25
4.4 Persistence	27
4.5 Summary	28
5. CONCLUDING COMMENTS	28
REFERENCES	30

1. INTRODUCTION

Drought, strikes, China, biofuels and the GFC have all been held responsible for the substantial rise, then fall and then rise again of commodity prices over the last 10 years. But as shown in Figure 1.1, this recent experience is by no means unique over the last 100 years. The possible qualification to this statement is the length of what is known as the “Millennium Boom” of prices that started in the early 2000s and ran for several years. Over much of history, commodity prices have been volatile with periods of dramatic booms and slumps with prices changing by as much as 50-100 percent in a single year.¹ Notwithstanding this long history, the major fluctuations recently experienced in international commodity markets have once again focused attention on the nature and functioning of these markets. Major issues include, how long can high prices be sustained? Is there excessive price volatility? Do prices reflect underlying fundamentals? To what extent has the role of commodities as financial assets changed the way in which they are priced? What is the role of speculators; do they smooth or amplify price fluctuations? These issues are of direct importance to commodity producers everywhere and governments in large-producing countries that rely on commodities for a substantial part of their revenue. In addition, those who consume food, energy and metal products – that is, everyone – are also indirectly affected by developments in international commodity markets. Using metals as a case study, this paper sheds light on several aspects of commodity prices – their determinants and their cyclicity in particular.

There are three major strands of the literature on commodity/metal prices. First, there are important measurement issues. A central question here is establishing the longer-term trend rates of change of prices, which has been the subject of much controversy, as documented in the papers collected in the book by Greenaway and Morgan (1999). Prior to the 2000s, a good rule of thumb was that these prices declined in real terms by about 1 percent per annum over the longer term. This contributed to the influential, but misguided, recommendation of Prebisch and his followers that as commodity exporters, developing economies could avoid a long-term deterioration in their terms of trade and incomes by reducing their reliance on trade by protecting their import-competing industrial sectors. Other measurement issues include the “excess

¹ For evidence on commodity-price fluctuations see, for example, Bresnahan and Suslow (1985), Cashin and McDermott (2002), Chu and Morrison (1984), Cuddington and Liang (2003), Deaton (1999), Deaton and Laroque (1992), Kroner et al. (1993), Reinhart and Wickham (1994) and Yamey (1992).

volatility” and the “excess comovement” of commodity prices (Pindyck and Rotemberg, 1990), as well as how to quality adjust the price deflator that transforms nominal commodity prices into their real counterparts.

A second strand of literature that deals indirectly with commodity prices is the intensity-of-use (IOU) approach to analysing consumption. This is frequently used for assessing the future prospects of metals consumption in particular and is popular with practitioners. This work is mostly associated with Tilton and his co-authors (see, for example, Radetzki and Tilton, 1990). Take the case of steel, for instance. Steel consumption per dollar of GDP typically exhibits an inverse U-shaped relationship with GDP per capita, growing at lower levels of income, reaching a peak and then declining as the economy matures and service sector starts to dominate. While prices would seem to play no role in this IOU approach when making projections of the steel consumption per dollar of GDP, a case can be made that this sort of projection forms an important context for thinking about the future course of metal prices. What new sources of supply would be required to satisfy the projected demands? And what prices would be needed to sustain this new production capacity? In this sense, the IOU approach is related to prices and possibly can be thought of as the price dual.

A third strand of literature deals with interactions between commodity and currency markets. Australia, New Zealand, Canada, Norway and a number of developing countries are commodity exporters. As an empirical regularity, their currencies tend to appreciate when commodity markets boom, and depreciate when they slump. Thus, the exchange rate serves as a key part of the adjustment mechanism as the appreciation means that the gain to domestic commodity producers is lower than otherwise, while consumers gain from the appreciation due to lower-priced imported goods. In such a case, the adjustment burden is shared between commodity producers and domestic consumers, and these countries are said to have “commodity currencies”.² Additionally, some countries are sufficiently large commodity exporters that they

² Prominent research on commodity currencies includes Amano and van Norden (1995), Blundell-Wignall and Gregory (1990), Blundell-Wignall et al. (1993), Broda (2004), Cashin et al. (2004), Chen and Rogoff (2003), Freebairn (1990), Gruen and Kortian (1998), Gruen and Wilkinson (1994), Hatzinikolaou and Polasek (2005), McKenzie (1986) and Sjaastad (1990). For theory on the dependence of the real exchange rate on the terms of trade, see Connolly and Devereux (1992), Devereux and Connolly (1996), Edwards (1988, 1989), Edwards and van Wijnbergen (1987) and Neary (1988). Closely allied to commodity currencies is the concept of booming sector economics, which is variously known as the Dutch disease, the Gregory effect and de-industrialisation. Important papers in this area include Corden (1984), Corden and Neary (1982), Gregory (1976) and Snape (1977).

have market power. An appreciation of the domestic currency squeezes local commodity producers, but because of their pricing power, they can “pass on” part of this to customers by increasing world prices. Here, the causation flows from currency values to commodity prices, the opposite direction to commodity currencies, so this approach is known as the theory of “currency commodities”.³ Clements and Fry (2008) combine the theory of currency commodities and commodity currencies to analyse the joint determination of exchange rates and commodity prices.

This paper is organised around “three facts” regarding metal prices. First, we consider the extent to which variations in metal prices can be accounted for by (i) global factors that are common to all metals and (ii) market-specific ones. The global factors could reflect world growth, liquidity and interest rates, while the market-specific factors represent everything else. More specific examples of global shocks are a slowing of growth in Chinese manufacturing and construction that substantially dampens world metals demand; central banks embarking on coordinated quantitative easing leading to a surge in global liquidity that inflates commodity prices; and a rise in energy prices that contracts the world economy. Market-specific shocks could include a technological breakthrough that makes lower-grade ore deposits commercially viable; strikes in major supplying countries; natural disasters disrupting metals production; and so on. Using the average of metal prices to measure the influence of global factors, we find that market-specific factors account for more than one-half of the variability of prices. Thus, *Fact One* is that metals prices are not dominated by global determinants. This could come as a surprise in view of the apparent common surges in prices that has occurred in recent years. This finding needs to be qualified, however, as global factors have increased in importance over the last four decades (but are still dominated by market-specific ones).

Fact Two relates to the pricing of specific metals. Prior research has identified a strong negative correlation between the price of a metal and the global volume produced/consumed in the corresponding year. This relationship is intriguing as it seems to hold for a wide variety of metals ranging from the cheapest such as iron ore, to the most expensive such as gold. The relationship also seems to endure over a long period of time, and is known as “Nutting’s Law”,

³ See, for example, Clements and Fry (2008), Clements and Manzur (2002), Dornbusch (1987), Gilbert (1989, 1991), Keyfitz (2004), Ridler and Yandle (1972), Sjaastad (1985, 1989, 1990, 1998a, b, 1999, 2000, 2001, 2008), Sjaastad and Manzur (2003) and Sjaastad and Scacciavillani (1996) and Swift (2004).

after Nutting (1977). The economic forces lying behind the law have not been fully articulated, though substitutability among metals in consumption seems to be emphasised. We re-examine the evidence underlying this issue and conclude that despite strident criticism raised by Evans and Lewis (2002, 2005), Nutting's Law is sufficiently promising to warrant further research and could possibly form the basis of a useful metals pricing model. But as there are still some uncertainties, we are unable to be hard and fast and, consequently, frame Fact Two cautiously as "Nutting's Law is (Possibly) not Nuts".

Fact Three is that metal prices are cyclical. Interest in measuring and dating economic cycles goes back to at least biblical times, when Joseph interpreted the dreams of Pharaoh to mean seven years of plenty followed by seven of famine. It is of considerable academic and practical interest to inquire whether metal prices cycle. Market analysts could find the information on cyclicality helpful in addressing the perennial questions of whether a current price boom is about to peak, or is a slump about to bottom out? Producers are also obviously affected by the state of the cycle: They want to know if they should add to capacity (no, if prices are about to peak); if they should hedge their production by locking in the current price, or take the chance that it still has not peaked and may go higher; or, if prices are expected to be low for a substantial period, should mines be put on "care and maintenance"? On the other side of the market, consumers could also have ways to respond to the knowledge of the state of the cycle, such as adding to or running down metal stockpiles. Finally, the public finances of governments in metal-producing regions can also be sensitive to prices and where they might stand in relation to the underlying cycle. For example, the state of Western Australia raised royalty income of about \$A4.2b in 2011, which is equivalent to about \$1,800 per capita, or 17 percent of state government revenue.⁴

Taken as a whole, the three facts assist with thinking about the evolution of prices. While Fact One states that global determinants do not dominate the pricing of metals, these determinants are nonetheless important and point to a set of common factors that drive prices, especially over the longer term. Along similar lines, the pervasive negative correlation between prices and volumes celebrated by Nutting's Law can assist with a fundamental understanding of pricing behaviour, even if there are still unknown aspects to the precise workings of this law.

⁴ Sources: WA Department of Treasury (2012a, b, c). For prior studies on the cyclical behaviour of metal prices, see Cashin et al. (2002), Davutyan and Roberts (1994), Labys et al. (1998) and Roberts (2009).

Finally, Fact Three helps interpret price behaviour over the short term. The cyclicity of prices is a strong empirical regularity that would seem to be of substantial academic and practical usefulness.

2. GLOBAL SHOCKS DO NOT DOMINATE

This section, which is based on Chen (2010, 2012), examines the broad sweep of metals prices over the longer term that leads to a simple split of prices into global and market-specific factors.⁵

2.1 The Data

To avoid the excessive detail involved in examining all metals traded internationally, we focus on the 21 major metals listed in column 1 of Table 2.1; these comprise the bulk of world mineral commodity trade. Data on prices from 1900 to 2007 and production from 1964-2007 are from the US Geological Survey (USGS).⁶ Let p_{it} be the price (in nominal US dollars) of metal i in year t and q_{it} be the corresponding volume of production. Then, $M_t = \sum_{i=1}^{21} p_{it}q_{it}$ is the total value and $w_{it} = p_{it}q_{it}/M_t$ is the value share of i . Table 2.1 shows the value shares for selected years and highlights the relative importance of iron/steel compared to the remaining 20 metals. Although in recent years this metal has declined in relative importance, it still accounts for almost 30 percent of the total in 2007. The metals with the largest increases in shares since 1964 include nickel (5.3 percent, as indicated by row 13, column 8 of the table), copper (3.2 percent) and aluminium (2.3 percent), while iron/steel falls by about 10 percent.

We deflate nominal prices by the US Consumer Price Index.⁷ Table 2.2 summarises the real price data with metals ranked by mean price change. Thus, for example, on average, molybdenum price grew (in real terms) by nearly 2 percent a year over the 1900–2007 period,

⁵ For related research, see Bidarkota and Crucini (2000).

⁶ The USGS provides times-series data on approximately 90 mineral commodities from more than 18,000 mineral producers and consumers around the world. Data including world production, US imports and exports value, real and nominal unit price in terms of US dollars are available from: <<http://minerals.usgs.gov/ds/2005/140/>>.

⁷ Before 1913, we use the Cost-of-Living Index from Rees (1961, p. 74), which is a Laspeyres index of the prices of food, clothing, home furnishing, rent, fuel and light, liquor and tobacco, and all other items. After 1913, we use the CPI-U from the US Bureau of Labor Statistics, available from: <<http://www.bls.gov>> [5 September 2012]. One potential problem with using the CPI is quality change, which according to the Boskin Commission's (Boskin et al., 1996) best estimate, leads to an upward bias of 1.1 percent p. a. This induces a corresponding downward bias in the relative prices of metals.

whereas magnesium prices decreased by 4 percent annually. Figure 2.1 plots the average price changes. There is substantial dispersion in prices: In some years, some prices increase by well over 100 percent, while at other times, the falls are of the same order of magnitude (columns 7 and 8 of Table 2.2). For example, cobalt price increased by 255 percent over 1907–1908 and then fell by 299 percent during the next 12 months.⁸ The volatility of returns is high with the standard deviation ranging from a low of 6 percent for iron/steel to a high of 49 percent for cobalt (column 6). Volatility averaged over the 21 metals for the period from 1900 to 2007 is more than 23 percent (last row of column 6). This large dispersion in price changes dominates small secular changes (column 2) in all cases. While average price changes vary quite dramatically across metals and there is much volatility, in the majority of cases, prices increase on average (although the mean over metals is near zero, as indicated by the last entry of column 2 of the table). This could suggest a role for common systematic factors in driving all prices, but clearly the volatility also allows for considerable scope for market-specific factors. The last column of Table 2.2 shows that in almost all cases (except copper and lead), price changes are not normally distributed (which is possibly due to the large outliers).

2.2 Two Indexes of Prices

Usually, price indexes are of the weighted variety in order to reflect the relative importance of the different commodities (to make them “representative”). However, in the case of metals, weighting is not possible due to the absence of quantity data from the earlier years of the sample period. Accordingly, we use an unweighted average of prices of the form $DP_t = 1/21 \cdot \sum_{i=1}^{21} Dp_{it}$, where $Dp_{it} = \log p_{it} - \log p_{i,t-1}$ is the annual logarithmic change in the deflated price of metal i . Quantity information is available from 1964 onwards, enabling us to compute the weighted price index $DP'_t = \sum_{i=1}^{21} \bar{w}_{it} Dp_{it}$, where $\bar{w}_{it} = 1/2(w_{i,t-1} + w_{it})$ is the average of the value share over years $t-1$ and t . The excess of the weighted over the unweighted index is $\sum_{i=1}^{21} (\bar{w}_{it} - 1/21) Dp_{it}$, so that

⁸ Note that these are logarithmic changes, defined as $Dp_{it} = \log p_{it} - \log p_{i,t-1}$. For small changes, $Dp_{it} \approx [(p_{it} - p_{i,t-1})/p_{i,t-1}]$, while the exact relationship is $100 \times (e^{Dp_{it}} - 1) = 100 \times [(p_{it} - p_{i,t-1})/p_{i,t-1}]$. Thus, for $Dp_{it} = -2.99$ for cobalt, the implied percentage change is $100 \times (e^{-2.99} - 1) = -95$ percent.

$$DP'_t - DP_t = \sum_{i=1}^{21} \left(\bar{w}_{it} - \frac{1}{21} \right) (DP_{it} - DP_t).$$

This reveals that the difference between the two indexes is proportional to the covariance between the weights and the relative price changes. Accordingly, the weighted index exceeds its unweighted counterpart when, on average, those goods with above-average weights experience increases in their relative prices, and when those with below-average weights have decreasing relative prices. Roughly speaking, if metals whose relative prices increase (decline) become economically more (less) important, then the weighted price index grows faster than its unweighted counterpart.⁹

Figure 2.2 presents the two indexes expressed in terms of levels with 1990 = 100. As can be seen from the period of the overlap (the shaded region), weighting does not seem to have a major impact on the broad trends, so the above covariance is near zero at least on average, although the weighted index is slightly less volatile. For instance, the rise in prices from the trough in 1970 to the peak in 1979 was 47 percent for the weighted index, compared with 91 percent for the unweighted index. Similarly, the fall from 1979 to 1986 was 34 percent based on the weighted approach, compared with 47 percent based on the unweighted approach. Given the high correlation between the two indexes (0.98), using the equally-weighted index for the longer period should be satisfactory.

2.3 Global and Commodity-Specific Shocks

Variations in metals returns may be the result of common movements in macroeconomic variables (such as global GDP and real interest rates) that affect the demand for or the supply of a broad set of metals, as well as commodity-specific factors that are unique to each metal. Conceptually, the former component cannot be diversified away by combining other metals in a portfolio, whereas the latter can. This sub-section sheds light on the relative importance of these two components.

⁹ A further analysis of the covariance involves a comparisons of the relative sizes of (i) the “direct” effect of the price change on the value share when the volume is held constant; and (ii) the “indirect” effect when the volume changes on account of the substitution effect. When the substitution effect is low, as it likely to be the case (especially in the short run), the direct effect dominates and the covariance is positive.

Asset pricing theory is a useful framework for analysing the evolution of the prices of commodities that are storable. Suppose the expected return on holding commodity i is a linear function of a single factor or a market index:

$$(2.1) \quad E(r_i) = r_f + \beta_i E(r_m - r_f),$$

where $E(r_i)$ is the expected rate of return on i ; r_f is the rate of return of a theoretical risk-free asset, representing the compensation required by investors for placing money in any investment; $E(r_m)$ is the expected return of a diversified market portfolio, associated with the pricing of market-wide risk; and β_i measures the sensitivity of the commodity's return to changes in system-wide global fluctuations. The idea behind model (2.1) is that investors require compensation for the time value of money and risk. Generally, a higher β_i corresponds to higher non-diversifiable risk of holding commodity i , and since investors are taken to be risk averse and require a higher return to compensate for holding a more risky asset, this leads to a higher expected return on i .

In the context of metals, we use the price change Dp_{it} as the annual return on i and the index DP_t as a proxy for the return on a portfolio of metals. Thus, we estimate

$$(2.2) \quad Dp_{it} = \alpha_i + \beta_i DP_t + \varepsilon_{it},$$

where $\alpha_i = (1 - \beta_i)r_f$, and ε_{it} is a zero-mean random disturbance that measures news that hits the market in year t , independent of DP_t . For simplicity, the risk-free return r_f on real metal prices is assumed to be constant over time. The single factor DP_t is interpreted as a proxy for macroeconomic, or global, risk, so the value for the coefficient of determination for the equation, R^2 , measures the fraction of the variation in the price that is attributable to global fluctuations, while $1 - R^2$ is the fraction due to commodity-specific factors that are independent of global factors. The parameters of this equation satisfy $\sum_{i=1}^{21} \alpha_i = 0$, $\sum_{i=1}^{21} \beta_i / 21 = 1$, so that the β_i 's average out to unity. For a metal drawn at random, the expected return coincides with that of the portfolio of metals; that is, $E(r_i) = E(r_m)$.

The individual prices, the mean and dispersion are plotted against time in Figure 2.3. As the points have a distinct tendency to move in synchronisation, this figure reveals that a common factor in price determination seems to play at least some role. Interestingly, there is also a

tendency for more dispersion in prices to be associated with large changes in the mean price, either up or down; this occurs, for example, in 1908, the early 1930s, the boom of the 1970s and again in the recent Millennium Boom. There is no “mechanical” reason for this “moment dependence” of prices, but it has also been observed in the inflation and relative price literature.¹⁰ A further feature of the figure is the rather distinct price behaviour in three “epochs”: 1900-1940, 1941-1970, and 1971-2007. The first and last epochs have relatively high price dispersion, while in the middle one there is much more tranquillity. Part of this middle epoch corresponds to the Bretton-Wood system of fixed exchange rates. The first epoch contained great shocks associated with World War I and the Great Depression; it also contained a period of floating exchange rates. With major currencies mostly floating for most of the modern epoch, does the evidence in Figure 2.3 provide a hint that floating rates go hand-in-hand with commodity-price volatility?

Figure 2.4 plots the return of each metal against the average return for the 21 metals. The solid lines are the least-squares regression lines. While there is substantial dispersion, for most metals there is no clear visual evidence against a linear relationship between Dp_{it} and DP_t . Table 2.3 presents the estimates of equation (2.2) with metals ranked according to the estimated slope coefficient, β_i , given in column 3. Cobalt has the largest slope coefficient of 2.54, indicating its price increases by more than 2 percent when the overall price index increases by 1 percent, so it is highly sensitive to worldwide macroeconomic factors. Conversely, boron is the only metal that has an insignificant β with a value of 0.16, implying that its price is almost completely insensitive to systematic global factors. All 21 metals have insignificant intercept terms except for magnesium. Columns 4 and 5 of Table 2.3 contain the R^2 and $1-R^2$. The R^2 's are also displayed in panel A of Figure 2.5. As $1-R^2$ is greater than 50 percent in all cases, and averages more than 75 percent, what stands out is the importance of commodity-specific risk. As pointed out above, the price of boron is insensitive to global shocks; thus its commodity-specific risk component accounts for almost all of the variations in its returns. On the other hand, the metals that have the highest global risk factors are iron and steel ($R^2 = 47$ percent) and copper ($R^2 = 45$ percent).

¹⁰ See, for example, Balk (1978), Clements and Nguyen (1981), Foster (1978), Glejser (1965), Parks (1978) and Vining and Elwertowski (1976).

As a check on the functional form, we added to model (2.2) a quadratic term:

$$Dp_{it} = \alpha'_i + \beta'_i DP_t + \gamma_i (DP_t)^2 + \varepsilon'_{it}.$$

As can be seen from column 8 of Table 2.3, the estimated γ_i coefficients are all very small and in 19 of the 21 cases, insignificant at the 5 percent level (iron/steel and cobalt are only significant here). Thus, linearity seems to be a not unreasonable form, which agrees with the visual evidence from Figure 2.4. Furthermore, the R^2 values in panel B are similar to those in panel A of Table 2.3, so the global vs commodity-specific decompositions are substantially unaffected by the addition of the quadratic term.

2.4 The Exchange-Rate Regime, Global Risk and Economic Importance

Previous research has identified currency values as important determinants of commodity prices. Relatedly, as Deaton and Laroque (1992) and Cuddington and Liang (2003) demonstrate, primary commodity prices tend to be more volatile under floating than fixed exchange rates, and the econometric implication of merging data from the two exchange rate regimes is unclear.¹¹ Therefore, to investigate the effect of a different exchange rate regime on the results, the sample period is divided into two sub-periods: (1) pre-1972 (1900–1971), corresponding to the fixed exchange rate regime; and (2) post-1972 (1972–2007), corresponding to the floating rate period. The results are shown in Table 2.4 with metals ranked according to the estimated slope coefficient over the pre-1972 period. All estimated intercepts are insignificant and are, therefore, not reported in the table. Over the two sub-periods, there is a large variation in the estimated slope coefficients and the global-risk proportions. Pre-1972, the estimated slopes are significant in 16 out of 21 cases (column 2), while post-1972, all these coefficients are significant except for boron (column 6). Panel A of Figure 2.6 contrasts the two sets of estimates and as can be seen, the dispersion is much larger in the pre-1972 period.

In addition, R^2 values are low during the pre-1972 period (panel B of Figure 2.5), implying the greater part of price volatility during this sub-period is the result of commodity-

¹¹ Commodity prices are linked to the exchange-rate regime in two steps. First, according to the theory of currency commodities (as opposed to commodity currencies), changes in the real value of the US dollar have profound effects on the prices of primary commodities in all other currencies; see Clements and Fry (2008) for details. Second, as Mussa (1986) has shown, real exchange rates have become considerable more volatile under the current floating-rate regime. Consequently, this higher volatility in exchange rates post Bretton-Woods translates into greater volatility of commodity prices.

specific risk factors unique to each individual metal. Panel B of Figure 2.6 shows that in the floating rate period, R^2 values are higher in 19 of the 21 cases (the exceptions are boron and tungsten), so global risk has become more important. This also shows that when moving from the first to the second sub-period, the average value of R^2 more than doubles, from 16 to 34 percent. While systematic risk factors have become more important over the floating-rate period, most of the price volatility is still accounted for by commodity-specific risk. The last column of Table 2.4 is another feature worthy of note. This contains the rank of metals according to their estimated β_i during the second sub-period. Of the 13 metals with β_i less than unity over 1900–1971, nine experience an increase in the second sub-period. Conversely, this slope decreases in five out of the eight cases when β_i is originally above unity. As a consequence, the range of the β_i 's decreases substantially over the two periods, from 3.5 down to 2.2, and the standard deviation of the β_i 's drops from 0.78 to 0.48 (panel A of Figure 2.6)

Finally, we investigate whether there is any relationship between the economic importance of a metal and its global-risk component. Figure 2.7 is a scatter plot of the R^2 's against the value shares. The more important minerals – iron/steel, aluminium and copper – tend to have larger global risk shares, and vice versa for the smaller ones. This correlation says nothing about causation, of course. A higher global share could drive economic importance, or the causation could equally plausibly run in the opposite direction.

2.5 Summary

The results of this section can be summarised as follows. First, although metal prices seem to have a common factor component, global factors play a smaller role than commodity-specific. Second, during the current floating exchange-rate regime, the volatility of metal prices has risen and the size of the global factor increased (but this is still less than the commodity-specific factor).

3. **NUTTING'S LAW IS (POSSIBLY) NOT NUTS**

This section uses a descriptive statistical/analytic approach to identify longer-term patterns, or empirical regularities, in the prices of 16 prominent metals that comprise the bulk of global mineral trade from 1950 to 2010. Our approach is to first summarise the data in the form of price and volume comparison matrices that provide a convenient way of making pairwise

comparisons of different metals. We then use these matrices to analyse the covariation between prices and volumes. The finding is a striking negative relationship, which is known as “Nutting’s Law”, after Nutting (1977). We evaluate the underpinnings of this law and conclude this intriguing relationship is probably worthy of further attention as a way of understanding the workings of metal markets. This section is mostly based on Chen and Clements (2012).

3.1 Multi-Metal Matrix (MMM) Comparisons

We consider the 16 metals listed in column 1 of Table 3.1. These metals represent the most valuable according to the data published by the US Geological Survey in 2010. We use the prices and volumes from the USGS; prices are expressed in terms of US dollars per metric tonne (which is equivalent to 1,000 kilograms), while volumes are in metric tonne.¹² This sub-section systematically compares one metal with another. For 16 metals, there are $1/2 \cdot 16(16-1) = 120$ distinct pairwise comparisons, which can be conveniently arranged in the form of a 16×16 matrix, $\mathbf{X} = [x_{ij}]$. We thus term these multi-metal matrix (MMM) comparisons. One specific way to formulate these comparisons would be the dollar value of metal i minus that of metal j , $p_i q_i - p_j q_j$. Obviously, when a metal is compared with itself, the comparison yields zero, so that $x_{ii} = 0$, $i = 1, \dots, 16$. Furthermore, as i compared with j is identical to the comparison of j with i , except for the sign, all pairwise comparisons satisfy a skew symmetric property, that is, $x_{ij} = -x_{ji}$, $i, j = 1, \dots, 16$. This means that the comparison matrix \mathbf{X} is skew symmetric, $\mathbf{X} = -\mathbf{X}'$.¹³

It is more convenient to use a logarithmic formulation, which yields a comparison matrix for year t , \mathbf{X}_t , that has $x_{ijt} = \log(p_{it} q_{it}) - \log(p_{jt} q_{jt})$ as the $(i, j)^{\text{th}}$ element, or

$$(3.1) \quad x_{ijt} = \log\left(\frac{p_{it} q_{it}}{p_{jt} q_{jt}}\right) = \log\left(\frac{p_{it}}{p_{jt}}\right) + \log\left(\frac{q_{it}}{q_{jt}}\right).$$

¹² The data to be considered in this section are annual for the 61-year period 1950–2010, from the USGS (<http://minerals.usgs.gov/ds/2005/140/>). The 16 metals used here are a subset of the 21 from the previous section. The $n=16$ metals are derived from the $n=21$ in two steps. First, we disregard the three metals whose volume data are missing for the early part of the period, boron (the publication of volume data commence in 1964), and silicon (1964) and vanadium (1960). Second, we eliminate (i) iron and steel, to avoid any double counting with iron ore (which is already included among the $n=16$ metals) and (ii) tungsten because its value share is so small. As the recorded price of sulfur in 2009 (\$1.7/t) seems to be an outlier, it is replaced by the Tampa price at the end of 2009 (\$30/t), as reported by USGS (2010).

¹³ Clements and Izan (2012) use an analogous matrix comparison approach to analyse the structure of pay schedules.

This shows that each value comparison can be decomposed into corresponding price and volume components. As we have a comparison matrix for each of the 61 years, to keep things manageable we average them to give the average comparison matrix $\bar{\mathbf{X}} = 1/61 \cdot \left[\sum_{t=1}^{61} \mathbf{x}_{ijt} \right]$. For convenience, the 16 metals are ordered from the most to the least valuable, where value is interpreted as the product of price and volume. Table 3.1 contains the upper triangle of this matrix, bordered by an additional row and column. The diagonal elements are suppressed as they are all zero, while the elements below the diagonal are to be interpreted as the negative of those above the diagonal. The first row of the table refers to iron ore and the elements are 31, 39, 72, ..., 379. These numbers are all positive and increasing, which reflects the ordering and the fact that iron ore is the most valuable metal. As the elements are logarithmic differences multiplied by 100, the first number in the row, 31, means that iron ore production is approximately 31 percent more valuable than that of aluminium (the second most valuable metal), 39 percent more valuable than copper, 72 percent more valuable than gold, and so on.

The last element in the first row of Table 3.1, 204, is the average of all elements in the row including the suppressed zero first element. To interpret this row average, average equation (3.1) over $j = 1, \dots, 16$:

$$(3.2) \quad x_{i \cdot t} = \frac{1}{16} \sum_{j=1}^{16} \log \left(\frac{p_{it} q_{it}}{p_{jt} q_{jt}} \right) = (\log p_{it} + \log q_{it}) - (\log P_t + \log Q_t).$$

The terms $\log P_t$ and $\log Q_t$ are price and volume indexes, defined as $\log P_t = 1/16 \cdot \sum_{i=1}^{16} \log p_{it}$ and $\log Q_t = 1/16 \cdot \sum_{i=1}^{16} \log q_{it}$. This $x_{i \cdot t}$ is the logarithmic difference between the value of metal i and the log of the geometric mean of the 16 values; equivalently, $\exp(x_{i \cdot t})$ is the ratio of the value of i to the geometric mean of the value of all metals. The differences $x_{i \cdot t}$ have a zero sum over the 16 metals, $\sum_{i=1}^{16} x_{i \cdot t} = 0$. The last column of Table 3.1 presents the 61-year averages of these differences for each of the 16 metals, $x_{i \cdot} = 1/61 \cdot \sum_{t=1}^{61} x_{i \cdot t}$. Thus, the first entry in this column, for example, states that on average for the period, the value of iron ore is approximately 204 percent greater than average for all metals, that of aluminium is 173 greater, that of copper is 165 percent greater, and so on. Since the metals are ordered from the most to the least valuable, the elements in column 18 always decrease as we move down the column and are positive (negative) for above-average (below-average) metals. Manganese and lead are located near the

average. The elements in the last column of Table 3.1 are plotted in Figure 3.1. Finally, the last row of Table 3.1 contains the column averages, which are the negatives of the row averages because of the skew symmetry.

We use a similar procedure to construct comparison matrices for prices and volumes and these are summarised in Table 3.2. This table has three panels that refer to values, prices and volumes. The last row of panel A reproduces the row averages from the last column of Table 3.1. The corresponding decade averages are given in the other six rows of that panel. The value of iron ore, for example, was 226 percent greater than average in the 1960s and 180 percent greater than in the 1990s. The values are reasonably stable for the more valuable metals, but are more variable for some of the others, such as tin, sulfur and platinum. The standard deviation of these values, given in column 18, decreased slightly over the whole period, from approximately 126 percent at the beginning to 121 percent at the end.

Panels B and C of Table 3.2 compare prices and volumes and are interpreted analogously to panel A. As everything is in logs, the elements in the three panels satisfy the identity that value = price + volume. In the vast majority of cases, for a given metal, prices and volumes have opposite signs, with magnesium and nickel being the major exception to the rule. Thus, a metal with an above-average price generally has a below-average volume.

3.2 A Simple Metals Pricing Model

Expression (3.2) gives for year t the average of the i^{th} row of the comparison matrix \mathbf{X}_t in terms of values; this is the logarithmic deviation of the value of metal i from the average value of all 16 metals. We define the analogous price and volume concepts as

$$(3.3) \quad x_{i,t}^p = \log p_{it} - \log P_t, \quad x_{i,t}^q = \log q_{it} - \log Q_t,$$

which satisfy $x_{i,t}^p + x_{i,t}^q = x_{i,t}$, as defined by equation (3.2). Note that these are relative prices and relative volumes, which are both dimensionless concepts.

Next, consider a regression of prices on volumes

$$(3.4) \quad x_{i,t}^p = \beta x_{i,t}^q + \varepsilon_{it}, \quad i = 1, \dots, 16, \quad t = 1, \dots, 61,$$

where ε_{it} is a zero-mean disturbance term. This equation has no intercept as prices and volumes are expressed as deviations from the means. The logarithmic formulation means that the slope β

is the elasticity of price with respect to volume, $\beta = \partial(\log p_i) / \partial(\log q_i)$, which is also known as the “price flexibility”. The pooled OLS estimator of this flexibility is $\hat{\beta} = \sigma_{p,q} / \sigma_q^2$, where

$$\sigma_{p,q} = \frac{1}{16 \times 61} \sum_{i=1}^{16} \sum_{t=1}^{61} (\log p_{it} - \log P_t)(\log q_{it} - \log Q_t) \quad \text{and} \quad \sigma_q^2 = \frac{1}{16 \times 61} \sum_{i=1}^{16} \sum_{t=1}^{61} (\log q_{it} - \log Q_t)^2$$

are the price-volume covariance and volume variance, respectively, which are means of the second-order counterparts of (3.3).

Panel A of Figure 3.2 is a scatter plot of $x_{i,t}^p$ against $x_{i,t}^q$ for $i = 1, \dots, 16, t = 1, \dots, 61$. The vast majority of the points are scattered around a downward-sloping line with slope of approximately -0.9. As shown in panel B of Figure 3.2, we see the same basic negatively-sloped relationship with a very similar estimate of the slope when we take out the time dimension by averaging. Rather than pooling the data over the 61 years, we can also estimate model (3.4) separately for each year, and Table 3.3 summarises these results. It is evident that the estimated slope has some tendency to increase over time, but it is still reasonably stable and falls in the modest range of between -0.8 and -0.9. Thus, if as an approximation we set the price flexibility to -1 and the random disturbance ε_{it} to its expected value of zero, model (3.4) takes a very simple form:

$$(3.5) \quad \log p_{it} = \log \bar{M}_t - \log q_{it},$$

where $\log \bar{M}_t = \log P_t + \log Q_t$, is the log of the geometric mean of values in year t .

According to equation (3.5), the price of metal i depends on two factors. The first is $\log \bar{M}_t$, which reflects the overall state of the metals market, as measured by values; this indicator of the state of the market contains both aggregate price and volume components. The elasticity of each price with respect to the market is unity, so prices move in proportion to the market. The second term is $-\log q_{it}$, which measures the impact of changes in the volume of metal i on its price; as the corresponding elasticity is -1, the price of a metal is inversely proportional to its volume. If, for example, the overall metals market grows by 10 percent in a year and the volume of metal i also increases by 10 percent, so that $\Delta \log \bar{M} = \Delta \log q_i \approx 0.10$, then the price of i will remain unchanged. It will increase (decrease) if its volume increases at a slower (faster) rate than that of the overall market. In other words, according to equation (3.5),

the price of a metal is a simple sum of a market-wide factor and a metal-specific factor. Alternatively, (3.5) can be written as

$$\log p_{it} - \log P_t = -(\log q_{it} - \log Q_t),$$

which expresses the relative price of metal i , $\log p_{it} - \log P_t$, in terms of the corresponding relative volume, $\log q_{it} - \log Q_t$. This shows that the relative price of i decreases (increases) if the relative volume increases (decreases). It is to be noted again that prices and volumes are (inversely) proportional.

3.3 Nutting's Law

Nutting (1977) used the following metal-pricing model

$$(3.6) \quad \log p_{it} = \alpha_t + \beta' \log q_{it} + \varepsilon'_{it},$$

where ε'_{it} is a disturbance term. Using data for 14 metals, he obtained an estimated slope coefficient of approximately -0.7.¹⁴ Nutting's work occupies a reasonably prominent place in the literature on metals pricing and the log-linear model (3.6) is known as "Nutting's Law". In view of definition (3.3), models (3.4) and (3.6) are the same, with

$$\alpha_t = \log P_t - \beta \cdot \log Q_t, \quad \beta = \beta', \quad \varepsilon_{it} = \varepsilon'_{it}.$$

This accounts for the broad similarity between Nutting's result of $\hat{\beta}' \approx -0.7$ and ours of $\hat{\beta}$ falling in the range -0.8 to -0.9.

Returning to Panel A of Figure 3.2, one notable pattern is the clustering of observations for each metal. This suggests that model (3.4) should be extended by adding a dummy variable for each metal to account for fixed effects:

$$(3.7) \quad x_{i,t}^p = \alpha_i + \beta x_{i,t}^q + \varepsilon_{it}, \quad i = 1, \dots, 16, \quad t = 1, \dots, 61,$$

where α_i is the metal-specific intercept. As $\sum_{i=1}^{16} x_{i,t}^p = \sum_{i=1}^{16} x_{i,t}^q = 0$, the intercepts and disturbances

¹⁴ See also Georgentalis et al. (1990), Hughes (1972) and Jacobson and Evans (1985). For critical comments on this research (to be discussed subsequently), see Evans and Lewis (2002, 2005).

of (3.7) satisfy $\sum_{i=1}^{16} \alpha_i = \sum_{i=1}^{16} \varepsilon_{it} = 0$.¹⁵ Table 3.4 contains the results for the whole period. It is evident that adding the fixed effects causes the estimated slope coefficient to become nearly zero (-0.07) and insignificant. Owing to the relatively limited variability of the data over time for each metal (which is evident in the clustering in panel A of Figure 3.2) and the large cross-sectional dispersion, the fixed effects act as a substitute for the volume variable, so that when both sets of variables are included, volumes play little or no role in price determination.

3.4 An Assessment

Does Nutting's Law make sense? Several comments can be made in this regard. First, regressing prices on volumes treats volumes as exogenous. This is usually thought to be a satisfactory approach for agricultural products with lengthy gestation periods, so that current supplies on the market are more or less unrelated to current prices. For a sampling interval of one year, a similar argument is also possibly applicable to metals. In such a case, equations (3.4) and (3.6) are interpreted as inverse demand models that give the price needed to sell a given volume of metal. However, they are a special type of inverse demands as the slope (the price flexibility) is the same for each of the 16 metals.¹⁶

¹⁵ The ordinary least squares estimates of α_i sum over metals to zero. To show this, it is convenient to write (3.7) as $y_{it} = \alpha_i + \beta x_{it} + \varepsilon_{it}$, $y_{it} = \alpha_i + \beta_{it} + \varepsilon_{it}$, $i = 1, \dots, n$, $t = 1, \dots, T$. Defining $\mathbf{y} = [y_{11}, \dots, y_{1T}, \dots, y_{n1}, \dots, y_{nT}]'$, $\mathbf{x} = [x_{11}, \dots, x_{1T}, \dots, x_{n1}, \dots, x_{nT}]'$, $\boldsymbol{\alpha} = [\alpha_1, \dots, \alpha_n]$, and $\boldsymbol{\varepsilon} = [\varepsilon_{11}, \dots, \varepsilon_{1T}, \dots, \varepsilon_{n1}, \dots, \varepsilon_{nT}]'$, we have $\mathbf{y} = \mathbf{D}\boldsymbol{\alpha} + \mathbf{x}\boldsymbol{\beta} + \boldsymbol{\varepsilon}$, where $\mathbf{D} = \mathbf{1}_T \otimes \mathbf{I}_n$ is an $nT \times n$ matrix, $\mathbf{1}_T$ is a $T \times 1$ column vector of unit elements and \mathbf{I}_n is an $n \times n$ identity matrix. The OLS estimators are (Greene, 2008, p. 195) $\hat{\boldsymbol{\alpha}} = [\mathbf{D}'\mathbf{D}]^{-1}\mathbf{D}'(\mathbf{y} - \mathbf{x}\hat{\boldsymbol{\beta}})$, and $\hat{\boldsymbol{\beta}} = [\mathbf{x}'\mathbf{M}\mathbf{x}]^{-1}\mathbf{x}'\mathbf{M}\mathbf{y}$, where $\mathbf{M} = \mathbf{I}_{nT} - \mathbf{D}(\mathbf{D}'\mathbf{D})^{-1}\mathbf{D}'$. As $\mathbf{D}'\mathbf{D} = T \cdot \mathbf{I}_n$, we have $\hat{\boldsymbol{\alpha}} = T^{-1}\mathbf{D}'(\mathbf{y} - \mathbf{x}\hat{\boldsymbol{\beta}})$. In scalar terms,

$$\hat{\alpha}_i = T^{-1} \sum_{t=1}^T (y_{it} - \hat{\beta} x_{it}) = \bar{y}_i - \hat{\beta} \bar{x}_i, \quad i = 1, \dots, n,$$

where \bar{y}_i and \bar{x}_i are means over time. As $\sum_{i=1}^n y_{it} = \sum_{i=1}^n x_{it} = 0$, the estimated fixed effects have a zero sum:

$$\sum_{i=1}^n \hat{\alpha}_i = T^{-1} \left[\sum_{i=1}^n \sum_{t=1}^T y_{it} - \hat{\beta} \sum_{i=1}^n \sum_{t=1}^T x_{it} \right] = 0.$$

¹⁶ For a rigorous analysis of this issue in the context of consumer demand theory, see Chen (2012). She establishes sufficient conditions for Nutting's Law to hold: First, the metals form a separable group of goods in the consumer's utility function. Second, the metal sub-utility function is additive in the n metals. Third, income elasticity of each metal is unity. These conditions are admittedly stringent. Chen also shows that the inverse of the price flexibility (that is, the own-price elasticity of demand) can be interpreted as a weighted-average of the price elasticities of the individual metals when the marginal utility of income is held constant (so the elasticities are of the Frisch variety), where the weights are budget shares. This analysis has parallels in a production-theory context when metals are treated as factors of production. Peter Hartley has suggested to us that a similar analysis could possibly be carried out with the characteristics framework of Becker and Lancaster.

Second, if we consider the reciprocal case of regressing volumes on prices, the estimated slope coefficient, $\hat{\lambda}$ say, would be different to the inverse of $\hat{\beta}$ from (3.4) or $\hat{\beta}'$ from (3.6), but the two regressions would have the same R^2 values and the slopes would satisfy $\hat{\lambda} \times \hat{\beta} = R^2$. Thus, the better the fit, the closer one slope would approximate the inverse of the other. See Berndt (1976) for details.

Third, there is a measurement perspective when there is less than complete information available. Suppose no data are available on the volume of a certain mineral, but we observe from, say, the London Metals Exchange, its price, p_{it} . Then, if we have some idea of the total value of all minerals, M_t , a rough way to estimate the value of the mineral in question might be to take it as some constant proportion, so that $p_{it}q_{it} = \phi M_t$, where ϕ is the factor of proportionality. This implies $\log q_{it} = \alpha_t - \log p_{it}$, where $\alpha_t = \log(\phi M_t)$. Here, any “error” in the price is offset by the volume moving in the opposite direction in order to maintain the proportionality relationship. But this can also be written as

$$\log p_{it} = \alpha_t - \log q_{it},$$

which is Nutting’s equation (3.6) with price flexibility $\beta' = 1$. If the underlying data were constructed in a manner that approximated this way, there would be a tendency for the estimated price flexibility to be -1, which is not too far from Nutting’s Law. Whilst not claiming this is necessarily the case, it seems worthwhile to raise the issue as a possibility.

Fourth, there is a further issue of supply-side influences. From the last row of Table 3.2, the minerals with the largest production volumes are iron ore, sulfur and aluminium, while platinum and gold have the smallest. This ranking agrees roughly with world endowments of these minerals.¹⁷ If the annual flow of production of a mineral is proportional to its endowment, then Nutting’s Law states that those minerals for which production is large have lower prices, and vice versa, may be reflecting supply-side considerations in addition to demand. According to this interpretation, Nutting’s Law is a reduced form equation whose coefficients are (potentially complex) combinations of more basic structural parameters.

Fifth, there have been some strident criticisms of Nutting’s Law. Evans and Lewis (2005) consider model (3.6) to be too rigid, which is a plausible criticism. We concur that the basic

¹⁷ See, for example, Haynes (2012) and Winter (2012).

model could possibly be further elaborated and extended. Evans and Lewis also make two other arguments. First, they question the exogeneity of volumes on the right-hand side of model (3.6), which was mentioned in the first point above. Endogeneity of volumes is a possibility and can be dealt with in the usual way by employing IV methods. Second, they argue that Nutting's Law may result from a spurious regression involving I(1) variables. This is unlikely in the context of model (3.4) as this involves *relative* prices on the left-hand side and *relative* volumes on the right; these variables are likely to be stationary, not I(1). Columns 2-5 of Table 3.5 contain panel unit root tests for prices and volumes. No matter which test is used, in all cases the null can be safely rejected, so variables are not nonstationary. Moreover, columns 6 and 7 of the table give the results of testing whether the residuals from (3.4), with the pooled OLS estimate of the slope β , have a unit root. Again this hypothesis can be rejected, which implies that a spurious regression is unlikely. But suppose for the purpose of argument that prices and volumes were nonstationary. In such a case, the pooled fully modified ordinary least squares estimator (PFM) is consistent and has a limiting normal distribution (Phillips and Moon, 1999). The PFM estimate of β is -0.856 with asymptotic standard error 0.064, which is very close to the above estimates. In any event, straightforward inspection of the cross-sectional relationship of panel B of Figure 3.2 indicates that Nutting's Law is not guilty of the spurious regression charge.¹⁸

Figure 3.2 reveals a striking relationship between mineral prices and volumes and seems to be too valuable to be discarded. Nutting's Law is attractive in its elegant simplicity and we regard it as possibly a useful pricing rule that is worthy of further attention. This cautious wording is designed to convey the idea of the potential and promise of Nutting's Law, but not at this stage an unalloyed endorsement.¹⁹

¹⁸ In their work designed to test and generalise prior research related to Nutting's Law, Evans and Lewis (2005) use dynamic demand functions (with quantities on the left-hand side and prices and income on the right) that have different elasticities across metals. Their estimated long-run price elasticities are of the order of -0.1 and not all are significantly different from zero (Evans and Lewis, 2005, Tables 4a and 4b); they are also unable to reject the hypothesis that the long-run price elasticities are identical across metals (p. 68). A price elasticity of 0.1 implies a price flexibility of $1/-0.1 = -10$, so that a 1-percent fall in production leads to a 10-percent price rise, which seems too high. For closely related criticisms of Nutting's Law, see Evans and Lewis (2002) who conclude "that most metals have a similar, but statistically different price elasticity of demand" (p. 103). As identical price elasticities is a sufficient condition for Nutting's Law (but not a necessary one), this finding would seem to be not decisively inconsistent with Nutting's Law.

¹⁹ In future research, Chen's (2012) work, described in footnote 16, could be drawn upon to analyse metals consumption using the framework of conditional demand (that is, within metals) and group demand (metals as a whole vis-a-vis other goods). This would allow individual metals to have different price elasticities, while the

4. PRICES CYCLE

Why might prices exhibit cyclical patterns? Metal markets are continually hit with shocks of all kind that affect prices. If demand is price inelastic, there will be large price changes in response to supply shocks in the short run; over the longer term when demand is likely to be more elastic, the price response will be more moderate. The impact of demand shocks on prices depends on the ability of producers to shut down/bring on capability. As capacity is more constrained in the short run than in the long run (when new mines can be brought into production, for example), again the result is a path of prices that fluctuates more in the short run, less in the long run. As shocks reoccur, there is likely to be a tendency for reoccurring patterns in prices, that is, for prices to cycle. In this section we provide fresh evidence that prices do indeed exhibit cycles that are fairly well defined and give rise to an intriguing set of empirical regularities.²⁰ We also introduce a new “moments approach” to measuring the cycle; this approach brings together all metals into a single portfolio and identifies common features of the cycle such as the degree of persistence of the metals portfolio from one phase of the price cycle to the next.

4.1 The Data

We use price data for six major non-ferrous metals, aluminium, copper, lead, nickel, tin and zinc.²¹ The prices are monthly from 1989/06 to 2012/04 and are expressed in US dollars of 2005 by deflating by the US Producer Price Index.²² Table 4.1 presents some summary statistics. As can be seen, over the past two decades, the prices of three metals fell in real terms

elasticity for the group would be a weighted average. This could lead to a version of Nutting’s Law that holds at the group level. This could conceivably be what Evans and Lewis (2002) have in mind when they state “if the slopes of the individual demand curves are not too different from [that of equation (3.6)], the slope of this latter function may provide a reasonable estimate of substitution rates for all metals following price changes” (p. 98). But it should be noted that there is no requirement for the slopes (elasticities) of the individual metals to be “not too different” under the condition of consistent aggregation.

²⁰ For prior studies on the cyclical behaviour of metal prices, see Cashin et al. (2002), Davutyan and Roberts (1994), Labys et al. (1998) and Roberts (2009).

²¹ These metals have been widely traded in the London Metal Exchange (LME) for a long time. The LME was founded in 1877 and only copper was traded at first. Lead and zinc were added and gained official trading status in 1920. The exchange was closed during World War II and re-opened in 1952. The range of metals traded was extended to include aluminium (in 1978), nickel (1979), tin (1989), aluminium alloy (1992), steel (2008), and the minor metals cobalt and molybdenum (2010). For the reason of sufficient and balanced price and volume data, only the first six metals are included in our study.

²² The US PPI is from <http://stats.oecd.org/Index.aspx?DataSetCode=REFSERIES>. The metal prices refer to the last trading day of the month, from Thompson-Reuters DataStream.

(aluminium, nickel and zinc), while those of the other three increased. Nickel prices are the most volatile with a standard deviation of more than 10 percent per month and aluminium prices are the most tranquil (SD about 6 percent). The greatest monthly change is about -48 percent for copper, which occurred in October 2008 when the nominal price dropped from \$6,419 to \$3,993 with the PPI virtually constant. As the Jarque-Bera statistics (given in the second last row of Table 4.1) are all greater than 10, we reject the hypothesis that price changes are normally distributed.

Let p_{it} be the price of metal i in month t and q_{it} be the corresponding volume. Then, $M_t = \sum_{i=1}^6 p_{it}q_{it}$ is the total value and $w_{it} = p_{it}q_{it}/M_t$ is the value share of i . As defined in Section 2, the Divisia price index is

$$(4.1) \quad DP_t = \sum_{i=1}^6 \bar{w}_{it} Dp_{it},$$

where $\bar{w}_{it} = 1/2 \cdot (w_{it} + w_{i,t-1})$ is the share averaged over months t and $t-1$. The volume of turnover on the LME is used as a measure of q_{it} .²³ Table 4.2, which gives the weights, shows that copper and aluminium are the two most important metals, followed by zinc, nickel, lead and tin.²⁴ The values of index (4.1) are summarised in the last column of Table 4.1. As some price changes tend to be offsetting, the index fluctuates less than most of its components. The correlations between metal prices are given in Table 4.3 and as can be seen, there is a fair degree of comovement among the prices, with correlations averaging about one-half. As expected, the price index is most highly correlated with copper and aluminium, the metals with the largest value shares.

²³ To reduce the large amount of noise, turnover is smoothed using a 7-point unweighted centred moving average. Prices are not smoothed. For a discussion of this issue, see Cashin et al. (2002) and Pagan and Sossounov (2003).

²⁴ These weights for 1990-2011 correspond reasonably closely with those derived from price and production data published by the US Geological Survey (<http://minerals.usgs.gov/ds/2005/140/>), as can be seen from the following comparison for the year 2010:

Source	Aluminium	Copper	Lead	Nickel	Tin	Zinc
LME	32.83	46.92	2.52	6.62	1.81	9.30
USGS	31.83	41.92	3.37	11.75	1.96	9.16

The USGS weights are from Chen and Clements (2012).

4.2 Properties of the Cycle

We use the Bry-Boschan (1971) algorithm to date the turning points in the levels of the six prices as well as the price index and Table 4.4 gives the results in the form of the dates of the peaks and troughs.²⁵ For convenience, we shall refer to the phase of the cycle from a peak to the next trough as a “slump” in prices and the subsequent recovery to the next peak as a “boom”. Figure 4.1 plots the price index and the shaded periods represent the slumps. The long expansion that commenced in the early 2000s is known as the “Millennium Boom”. It is clear that this boom was unusually long, and can possibly be described as the dominant feature of the whole period. Prior to the Millennium Boom, slumps were mostly longer than booms. The prominence of the Millennium Boom can also be seen in the behaviour of the prices of the individual metals in Figure 4.2, but now for a couple of metals it does not last quite so long.

Some characteristics of phases of the cycle are summarised in Table 4.5 and two features are worth noting. First, the average duration of both phases of the cycle is longest for tin – 30 months for the slump and 22 for the boom. The shortest slump is for copper (13 months), while lead has the shortest boom (15 months). Second, the swings in prices are substantial over the cycle: From column 4, on average, prices fall by one-half or more in the slumps, while the average monthly amplitude for slumps and booms is about 3 percent (columns 5 and 10). In most cases, the (total) amplitude of the boom is greater (in absolute value) than that for the slump (compare columns 4 and 9). The largest amplitude is for nickel (in both slumps and booms), which is mostly attributable to the substantial increase and then collapse of its price in the second half of the 2000s.

Something interesting can be said about the nature of the path of prices over the cycle. Following Harding and Pagan (2002), let $a > 0$ and d represent the amplitude (in logarithmic terms) and duration (in months) of some slump in the price of a certain metal, so that a/d is the corresponding average monthly rate of decline. Consider the hypotenuse of the triangle with

²⁵ The algorithm involves the following steps: (i) The identification of possible peaks (troughs) as local maximum (minimum) using a window comprising the previous five and the next five months. (ii) Censoring of the peaks and troughs with three rules. (a) Peaks and troughs must alternate – when there are two consecutive peaks (troughs), the higher (lower) of the two is kept. (b) Peaks and troughs in the last 6 months and the first 6 months of the sample period are eliminated. (c) A phase (that is, a boom or a slump) must last for at least 6 months, and a cycle (the combined period of the boom and slump) must last at least 15 months. We use Adrian Pagan’s Excel program to implement this algorithm.

height a and base d , as shown in panel A of Figure 4.3. When the actual price path lies on this hypotenuse, it is falling at a constant rate a/d ; when it is always lies outside the hypotenuse, the path is concave (on average, at least) and initially the price falls by less than average and then as the slump proceeds, it falls faster; and when the path lies everywhere inside the triangle, the price initially collapses (falls faster than average) and the rate of decline then tapers off. These three cases are illustrated in panel B of Figure 4.3. A summary measure of the degree of departure from a constant rate of change is given by the area between the actual price path and the hypotenuse of the triangle, which is the excess of the observed cumulative change, $C > 0$, over the area of the triangle, $C - 1/2 \cdot a \cdot d$. When this excess is zero, we have the constant rate of growth case; and when it is positive (negative), the path is concave (convex), as illustrated in the left (right) parts of panel C of the figure. When the price path crosses the hypotenuse, as in the middle part of panel C, which refers to a boom phase, the sign of the excess determines which pattern dominates.

To make it independent of duration, the above excess is normalised by dividing by d to give the excess index, $(C - 1/2 \cdot a \cdot d)/d$, which, when multiplied by 100, is (approximately) in terms of percent per month. Columns 6 and 11 of Table 4.5 contain this index for each metal in slumps and booms. As the majority of values of the index are negative, the implication is that most paths lie inside the triangle, so that price movements around peaks are usually steeper than those close to troughs. This pattern is opposite to that typically found for GDP, which tends to grow rapidly immediately following a trough and then drop off as the peak approaches (so that the path lies outside the triangle). This is an interesting empirical regularity for metals that may be of some use in identifying a forthcoming peak. Note also that the excess indexes do not differ greatly for slumps and booms, so from this perspective there is no obvious asymmetry in prices over phases of the cycle.

Figure 4.4 contains histograms of duration and amplitude for all metals. Though there are several outliers, again there seems to be a certain degree of symmetry across slumps and booms. Next, we can measure the degree to which phases occupied by different metals coincide by the concordance index (Harding and Pagan, 2002). Define the binary variable $S_{it} = 1$ if the price of metal i is in a boom at time t and $S_{it} = 0$ for a slump. If there are T observations, the concordance of metals i and j is then

$$\frac{1}{T} \left[\sum_{t=1}^T S_{it} S_{jt} + \sum_{t=1}^T (1 - S_{it})(1 - S_{jt}) \right],$$

which is the fraction of time the two metals are in the same phase. As can be seen from Table 4.6, the largest concordance index is 89 percent for aluminium and the price index, which means that for almost 90 percent of the time the price of this metal and the index are simultaneously in either a boom or a slump phase of the cycle. The second largest is for copper and the index. This is understandable in view of the large weights of these metals in the index. The least concordant pair of metals is tin and zinc, whose prices are in different phases about $100 - 63 = 37$ percent of the time. The most concordant pair of individual metals is aluminium and zinc (81 percent of the time in the same phase).

The high concordances point in the direction of substantial comovement of metal prices, or the existence of an underlying common cycle. This can also be seen from Figure 4.2, where the “striped” pattern is quite similar across metals. A further way of examining this issue is via plots of duration and amplitude (DNA) of booms and slumps; these plots are an alternative way of expressing the chronology of prices. Figure 4.5 is a DNA plot for aluminium prices for both the booms (above the zero axis) and slumps (below zero), while Figure 4.6 gives the DNA of booms for all six metals. Looking at Figure 4.6 vertically, the commonality of the timing of booms is apparent, again suggesting a common cycle.²⁶

Cashin et al. (2002) and Labys et al. (1998) have also studied the cyclical nature of metal prices and we conclude this subsection with a brief comparison of their findings with ours. Cashin et al. (2002) use monthly data for the period 1957-1999 and consider a large number of commodity prices, including our six metals. They specify cycles must be at least 24 months long and phases at least 12 months, whereas for us, a cycle must be at least 15 months and a phase 6 months. This choice will have some influence on the results. Labys et al. (1998) consider only five metals and only the results for amplitudes of booms are presented. The points in the right-hand part of panel A of Figure 4.7 all lie below the 45-degree line, which shows that Cashin et al. find average durations to be somewhat longer than we do, as expected. But the left-hand part of this panel reveals that durations from Labys et al. are of the same order of magnitude as ours.

²⁶ For a further analysis of this issue, see Clements and Gao (forthcoming).

Panel B of the figure shows that our measures of amplitudes are larger than those of Cashin et al., but roughly similar to Labys et al.

4.3 A Moments Approach

In this subsection we analyse the cycle by considering the moments of the distribution of the duration and amplitude of the phases. Let d_{ie} and a_{ie} be the duration and amplitude of a phase of the cycle for the price of metal i in episode e . In the context of n metals, we consider the n durations, d_{1e}, \dots, d_{ne} , and the n amplitudes, a_{1e}, \dots, a_{ne} . The cross-metal means for $n = 6$ are

$$D_e = \frac{1}{6} \sum_{i=1}^6 d_{ie}, \quad A_e = \frac{1}{6} \sum_{i=1}^6 a_{ie},$$

and the corresponding variances are

$$V_{d,e} = \frac{1}{6} \sum_{i=1}^6 (d_{ie} - D_e)^2, \quad V_{a,e} = \frac{1}{6} \sum_{i=1}^6 (a_{ie} - A_e)^2.$$

The means measure the centre of gravity of the length and extent of the phases, while the variances refer to dispersion around the centre. We can also consider the relationship between duration and amplitude with the covariance

$$C_{da,e} = \frac{1}{6} \sum_{i=1}^6 (d_{ie} - D_e)(a_{ie} - A_e).$$

This covariance is positive when, on average, longer booms entail larger price increases or when shorter booms entail smaller price increases. In the case of slumps $a_{ie} < 0$, and when prices fall by more and duration is longer, $C_{da,e} < 0$.

As a boom ends when the price peaks, it might be thought that longer booms automatically entail larger price increases, so that the covariance $C_{da,e}$ is always positive for booms (and, by the same logic, always negative for slumps). Such is not the case, however, as can be demonstrated as follows. Consider the situation where amplitude is proportional to duration, $a_i = g_0 d_i$, $i = 1, \dots, n$, $g_0 = \text{constant} > 0$. The left-hand side of Figure 4.8 gives for one hypothetical metal a DNA triangle with base equal to the duration of a boom, height equal to amplitude and the slope of the hypotenuse is amplitude per month, g_0 . As amplitude is measured logarithmically, $g_0 = a/d$ is the average (monthly) growth rate, which we shall refer to as “growth” for short. In the right-hand side of the figure, superimposed on the previous triangle is

a larger one for a second metal for which duration is longer (d') and amplitude proportionately higher ($a' = g_0 d'$). Thus, growth is the same as for the first metal and the new triangle is similar to the old one. If this pattern of constant growth were to hold for each of the $i = 1, \dots, n$ metals, then the covariance $C_{da,e}$ would be positive. The covariance is also positive if when duration is longer, growth is higher rather than being constant. But if growth is lower, this covariance can be of either sign.

To analyse the nature of the covariance further, define growth for metal i in episode e as $g_{ie} = a_{ie}/d_{ie}$. The associated mean and variance are

$$G_e = \frac{1}{6} \sum_{i=1}^6 g_{ie}, \quad V_{g,e} = \frac{1}{6} \sum_{i=1}^6 (g_{ie} - G_e)^2.$$

There are now three variables that characterise the phase, d_{ie} , a_{ie} and g_{ie} . Clearly, these variables are not independent and there are three covariances: $C_{da,e}$ given above and

$$C_{dg,e} = \frac{1}{6} \sum_{i=1}^6 (d_{ie} - D_e)(g_{ie} - G_e), \quad C_{ag,e} = \frac{1}{6} \sum_{i=1}^6 (a_{ie} - A_e)(g_{ie} - G_e).$$

These covariances can also be expressed as

$$C_{dg,e} = A_e - G_e D_e, \quad C_{ag,e} = \frac{1}{6} \sum_{i=1}^6 a_{ie}^2 d_{ie} - G_e A_e, \quad C_{da,e} = \frac{1}{6} \sum_{i=1}^6 d_{ie}^2 a_{ie} - D_e A_e.$$

The right-hand side of each expression is the difference between two positive quantities, which can be of either sign. Table 4.7 illustrates the four possible configurations of the corresponding correlations ρ_{da} and ρ_{dg} . The important aspect here is that when growth is proportionate (scenario 4 of the table), the duration-amplitude correlation $\rho_{da} > 0$, while the duration-growth counterpart $\rho_{dg} = 0$. This shows that only the duration-growth correlation properly discriminates between proportionate and disproportionate growth.

Table 4.8 gives the moments for metals in both the booms and slumps. Several features of this table are worth noting. First, from columns 2 and 5, the standard deviation of duration tends to rise with mean duration in a more or less proportionate way for both booms and slumps, so that the longer the phase, the greater the dispersion. A similar pattern also holds for amplitude (columns 3 and 6), but not for growth (columns 4 and 7). Second, the average correlation between duration and amplitude during slumps is -0.74 (last entry of column 8), so longer slumps are also larger slumps (prices fall by more). For booms, these characteristics are

independent (mean coefficient = 0.08). Third, growth tends to be lower for more lengthy booms and less negative for longer slumps, but the relationship is not particularly strong (from column 9, the average correlations are -0.41 and 0.36 for booms and slumps, respectively). Fourth, conforming to expectation, amplitude and growth are positively correlated, as shown in column 10.

4.4 Persistence

Finally, we investigate the persistence of prices across phases of the cycle. Are longer slumps followed by longer and larger booms that “make up” for the losses of the past? Do symmetric patterns hold for the transitions from booms to slumps? Table 4.9 sheds some light on these issues by giving the cross-autocorrelations for duration, amplitude and growth. Three features stand out from this table. First, from the second element of column 3 (-0.663), there is some evidence of dependence between the amplitude of prices in the previous boom and that of the current slump. Thus, on average, a larger run-up of prices in boom times is associated with a greater subsequent slump; the negative sign of the correlation here reflects the change in the sign of amplitude in going from a boom to a slump. However, from the fifth element of column 3, there is almost no evidence of the symmetric effect holding for the transition from a slump to a boom. That is, the magnitude of the recovery of prices is independent of the size of the prior slump. The source of this asymmetry is unclear and could be explored in future research.

The second feature of Table 4.9 is that there is little or no duration dependence across phases, so that longer booms (slumps) are not associated with longer subsequent slumps (booms); the relevant correlations are only -0.156 and -0.236, from the first and fourth elements of column 2. In fact, all features of the current phase (duration, amplitude and growth) are more or less independent of the length of the past phase. The only exception is that there is a reasonably sized correlation between the duration of past slumps and growth in subsequent booms (correlation = 0.639, the fourth element of column 4). A third feature is that previous growth is also unrelated to all subsequent phase characteristics, with one exception that higher growth of past boom tends to be associated with a larger subsequent slump in prices (correlation = -0.681, the third element of column 3).

4.5 Summary

Using the metal price index to summarise the results, the boom phase of the cycle lasts for about 24 months on average, while the slump is about 16 months. There is some dispersion of duration across the different metals. On average, in the upswing prices increase on average by more than one half, most of which is lost in the subsequent downswing. The Millennium Boom of the 2000s was unusually long for all metals; if that period is excluded, then on the basis of the price index, the duration of the average boom falls from 19 months to about 12 months. Prices tend to change faster around the peak, slower around the trough. Thus, rapidly accelerating prices may indicate a forthcoming peak, while a moderation of price falls may signal a looming bottoming out of the slump. There is some evidence of some persistence in the behaviour of prices from one phase of the cycle to the next. A larger boom in prices is associated with a larger subsequent slump. There is, however, little or no indication that a longer boom (or slump) is followed by a longer slump (boom).

These empirical regularities could be useful in helping to understand the workings of metal markets. They may also be used to evaluate economic models of price determination – do the predictions of the models reproduce these empirical regularities? Such models would have to include several key features including the forward-looking nature of pricing on account for the durability of metals, so that expectations about the future course of events are an important component of pricing; the role of large stocks in buffering production and consumption; global factors that, in part at least, drive prices; the increasing metal intensity of GDP in emerging economies; the inelasticity of short-run metal supply curves due to more or less fixed capacity; and the substantial lags involved in bringing into production new mines due to high capital costs, the requirements for new infrastructure and lengthy approval processes.

5. **CONCLUDING COMMENTS**

This paper has analysed the pricing of metals in international markets. We used a “three-facts” framework that identified the following as important aspects of pricing behaviour:

- *Fact One* is that global determinants of prices do not dominate market-specific ones.
- *Fact Two* deals with a simple pricing rule. In its simplest form, the relative price of a metal is inversely proportional to its relative volume of production. Thus, if, for example,

iron ore production expands 10 percent faster than the average for all metals, then its price in terms of all metals falls by 10 percent.

- *Fact Three* is that prices exhibit well-defined short-term cycles that tend to repeat themselves.

Of course, these facts are somewhat styled and should not be taken to be iron-clad truths providing absolute guarantees to the future. Each fact comes with its own nuances, uncertainties and qualifications. The diminished role of globalisation implicit in Fact One may seem surprising, but it needs to be appreciated that here global factors are represented by an average of all metal prices. As most of the idiosyncratic influences wash out in the average price, the global factors are more or less orthogonal to market-specific determinants. Moreover, although the share of global determinants in price variability is less than the metal-specific component, global factors have become more important over that the last 40 years. This accords with prior expectation regarding the growth of globalisation. Similarly, the pricing rule of Fact Two is subject to the qualification that the underlying economic mechanisms are still not fully understood, and the evidence is regarded as controversial in some quarters. Consequently, this price-inversely-proportional-to-volume “fact” should probably be more accurately described as a “potentially promising/useful fact” that should be subject to further research. Finally, although the cyclicity of prices (Fact Three) seems to be a strong empirical regularity, the precise nature of each cycle has many of its own characteristics layered on top of the “average” cycle. Consequently, the cycle cannot be relied upon to exactly reproduce itself in the future, which is a feature of much of history as a whole.

Bearing in mind these qualifications, the three facts would seem to offer considerable insight into the workings of world metal markets and be useful for both theory and practice.

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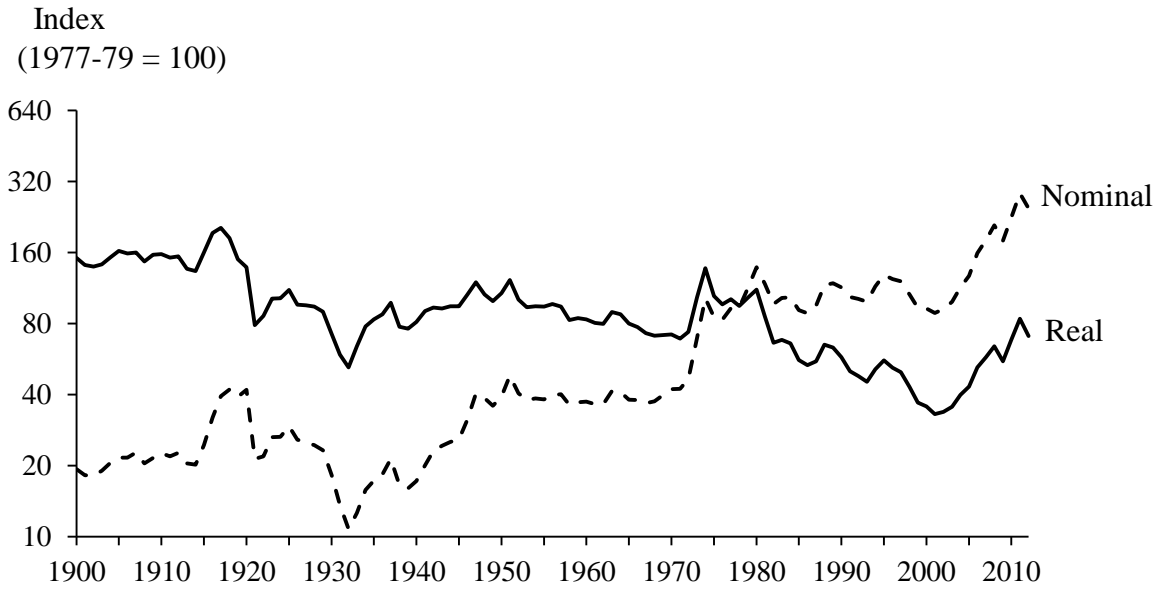
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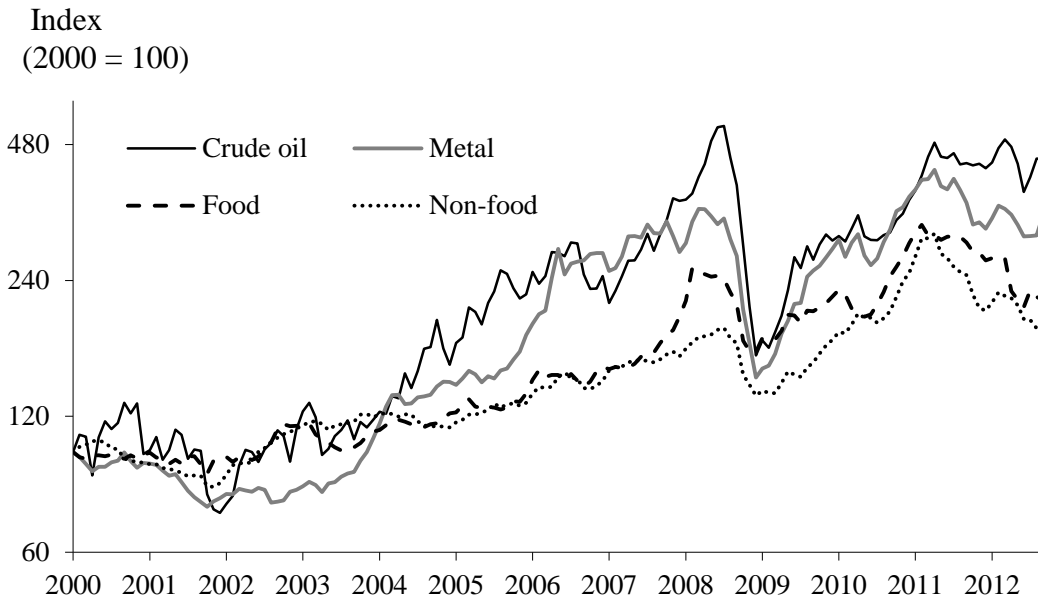
FIGURE 1.1

PRIMARY COMMODITY PRICE INDEX

A. Non-Fuel Commodity Price Index, 1900-2012



B. Millennium Boom: Commodity Sub-indexes, Nominal, 2000-2012



- Notes: 1. Data for 1900-1986 are from Grilli and Yang (1988), and 1987-2003 from Pfaffenzeller et al. (2007). Thereafter, updated to September 2012 by the authors using data from the World Bank and IMF. The commodity jute, which absorbs about 0.2 percent of the weight in the index, is excluded after 2003 because of unavailable data.
2. As the CPI, PPI and MPI all exhibit broadly similar trends, only the CPI-deflated index is shown in panel A as the real index.

TABLE 2.1
VALUE SHARES, 21 METALS, 1964-2007

Metal	Value share						Change 1964-2007
	1964	1974	1984	1994	2004	2007	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (7) - (2)
1. Aluminium	9.89	12.58	10.81	13.17	12.77	12.20	2.31
2. Boron	0.09	0.07	0.95	1.30	1.07	0.43	0.34
3. Chromium	0.51	0.72	1.09	0.94	1.75	1.59	1.08
4. Cobalt	0.18	0.23	0.40	0.33	0.59	0.43	0.25
5. Copper	10.12	12.14	5.87	10.16	10.02	13.28	3.16
6. Gold	5.01	6.45	8.64	12.24	7.37	6.36	1.35
7. Iron/Steel	38.75	34.53	37.97	36.16	36.09	29.23	-9.52
8. Iron ore	17.59	13.97	16.87	10.92	11.90	14.43	-3.16
9. Lead	2.42	1.74	0.92	1.00	0.90	1.23	-1.19
10. Magnesium	0.38	0.22	0.55	0.44	0.48	0.44	0.06
11. Manganese	1.82	1.49	1.77	1.72	2.49	1.79	-0.03
12. Molybdenum	0.40	0.40	0.39	0.49	1.35	1.63	1.24
13. Nickel	2.06	2.97	1.88	2.58	4.52	7.36	5.31
14. Platinum	0.46	0.90	0.97	0.98	1.61	1.37	0.90
15. Silicon	1.41	1.54	1.29	1.55	1.78	0.96	-0.45
16. Silver	1.02	1.41	1.75	1.04	0.95	1.36	0.34
17. Sulfur	1.48	1.46	2.52	0.70	0.50	0.30	-1.19
18. Tin	2.19	2.04	1.32	0.63	0.83	0.76	-1.43
19. Tungsten	0.25	0.40	0.27	0.14	0.18	0.23	-0.02
20. Vanadium	0.10	0.17	0.22	0.16	0.28	0.20	0.10
21. Zinc	3.84	4.60	3.56	3.36	2.57	4.42	0.58
Total	100.00	100.00	100.00	100.00	100.00	100.00	0.00

Note: All entries are to be divided by 100.

TABLE 2.2
SUMMARY STATISTICS OF REAL METAL PRICES, 21 METALS, 1900-2007
(Annual log-changes $\times 100$)

Metal	Mean	Median	Standard deviation			Minimum	Maximum	p-values for Jarque-Bera Statistics
			1900-71	1972-07	1900-07			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. Magnesium	-4.16	-2.93	15.68	16.25	16.26	-87.61	56.69	0.00
2. Sulfur	-1.77	-1.38	17.97	30.08	22.63	-93.23	86.63	0.00
3. Aluminium	-1.76	-1.14	16.16	20.60	17.70	-59.87	59.40	0.00
4. Boron	-1.00	-1.80	31.77	7.33	26.17	-177.69	100.69	0.00
5. Cobalt	-0.75	-0.99	55.71	33.92	49.34	-299.15	255.22	0.00
6. Vanadium	-0.70	-2.42	20.16	41.48	29.70	-103.19	97.16	0.00
7. Copper	-0.18	-0.65	17.84	20.07	18.53	-44.10	56.39	0.81
8. Iron ore	0.03	0.15	16.73	10.09	14.78	-41.12	96.73	0.00
9. Lead	0.09	0.06	16.25	20.34	17.67	-44.32	45.61	0.80
10. Silver	0.10	-1.70	14.14	28.21	19.92	-77.18	61.24	0.00
11. Tin	0.18	0.19	19.76	20.09	19.78	-59.45	62.76	0.03
12. Nickel	0.29	-1.10	8.11	28.55	17.75	-45.88	100.72	0.00
13. Zinc	0.33	-0.53	20.91	22.91	21.52	-58.64	101.78	0.00
14. Iron/Steel	0.33	-0.40	4.01	6.65	5.55	-10.33	26.96	0.00
15. Silicon	0.34	0.03	17.33	15.51	16.52	-60.63	46.38	0.00
16. Chromium	0.35	0.59	21.14	21.78	21.29	-70.81	56.98	0.00
17. Gold	0.37	-1.45	7.65	21.60	14.04	-38.42	56.25	0.00
18. Manganese	0.68	-0.34	24.36	18.69	22.60	-101.47	62.98	0.00
19. Tungsten	0.90	1.44	31.23	27.15	29.79	-97.91	137.63	0.00
20. Platinum	1.41	1.61	21.21	23.99	22.07	-73.75	112.90	0.00
21. Molybdenum	2.04	-0.87	36.31	42.53	38.58	-110.10	122.63	0.00
All metals	-0.13	-1.00	23.62	24.29	23.86	-299.15	255.22	

Notes: 1. The prices of five metals are not available for the whole period: iron and steel is available from 1940-2007, magnesium from 1915-2007, molybdenum from 1912-2007, silicon from 1923-2007 and vanadium from 1910-2007.

2. The Jarque-Bera statistic tests normality. For sample size 100, the exact p-value for $\alpha = 0.05$ is $p = 0.06$.

FIGURE 2.1
 AVERAGE ANNUAL GROWTH OF RELATIVE METAL PRICES,
 21 METALS, 1900-2007

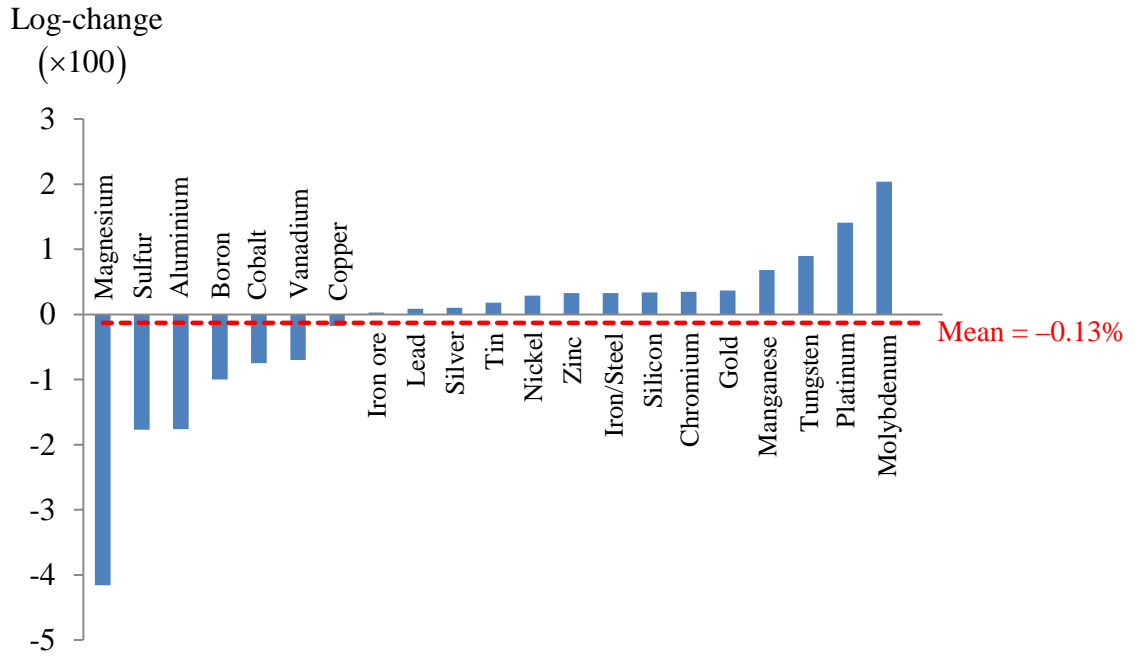


FIGURE 2.2
 TWO METAL PRICE INDEXES, REAL, 1900-2007

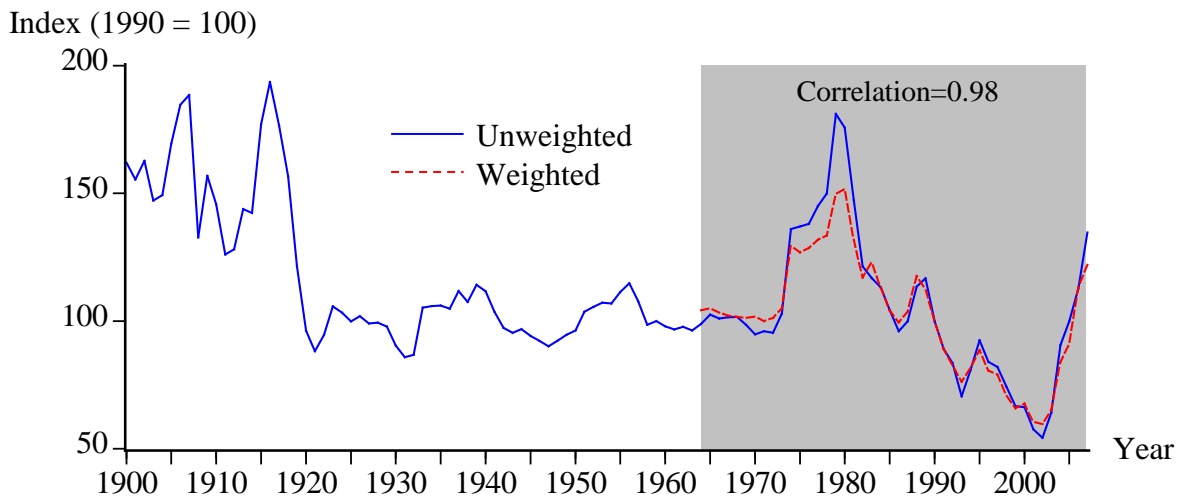
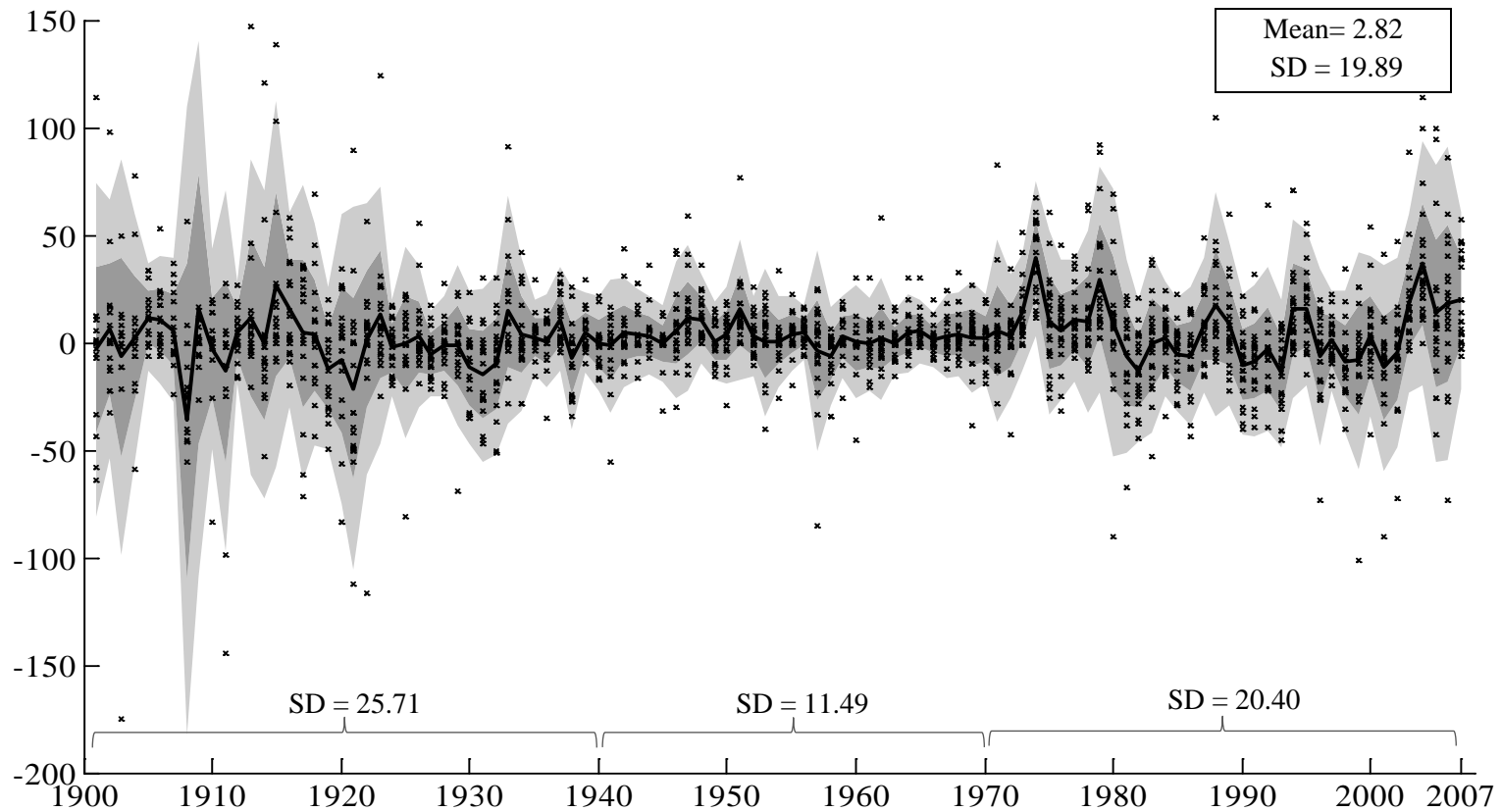
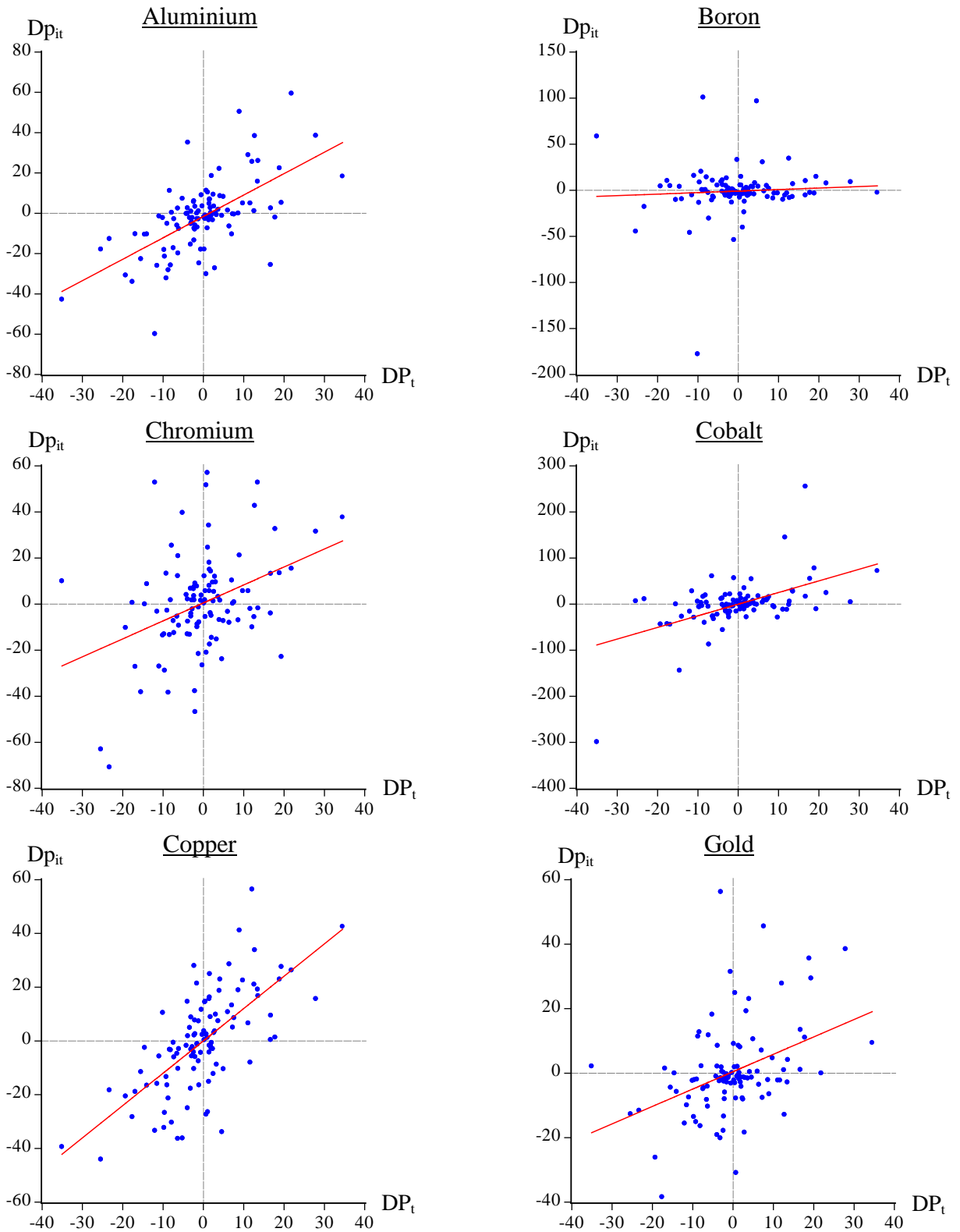


FIGURE 2.3
 RELATIVE PRICES OF 21 METALS, 1900-2007
 (Annual logarithmic changes $\times 100$)



- Notes:
1. For each year, the changes in the 21 prices are represented by 21 points.
 2. The solid dark line represents the average change in prices. The dark grey band is the mean \pm one (cross-sectional) standard deviation, and the light grey band is the mean \pm two standard deviations.
 3. To enhance the visualisation, two observations are omitted: The price change of cobalt from 1907-1908 (log-change $\times 100 = -299$) and 1908-1909 (255) .
 4. SD is the average over time of the cross-sectional standard deviations.

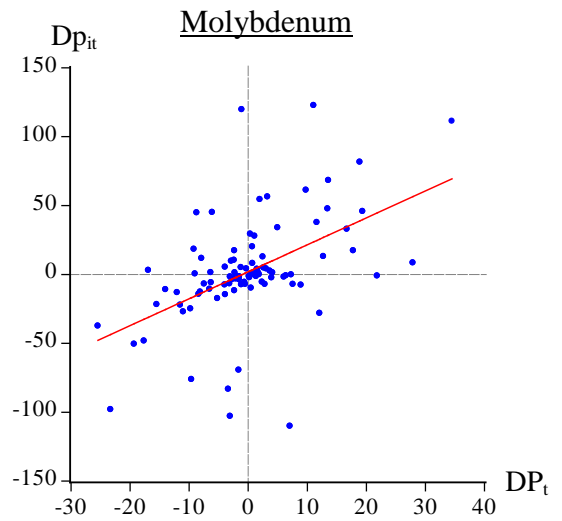
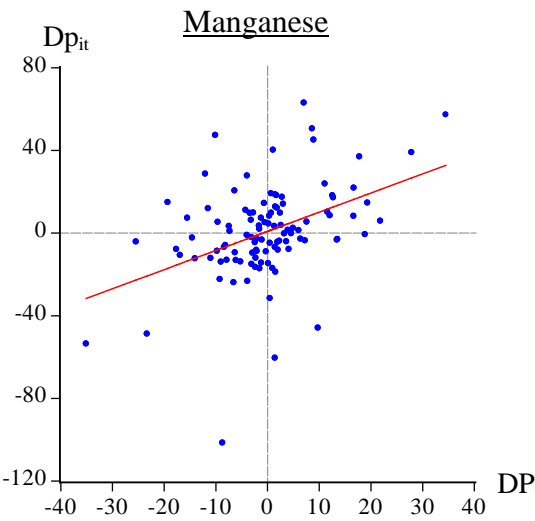
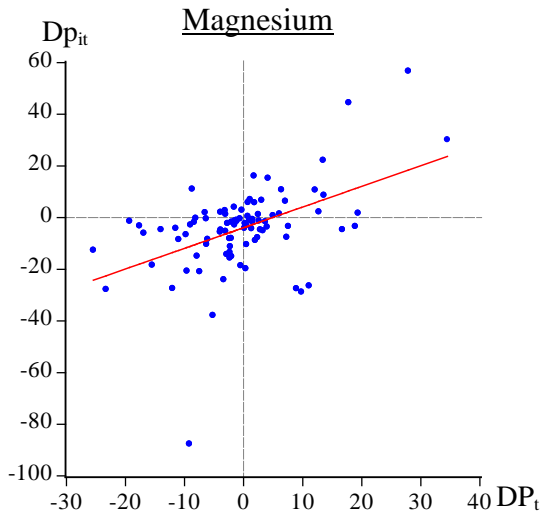
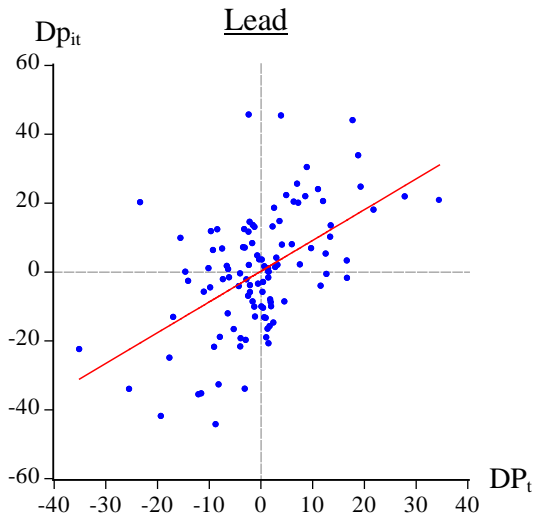
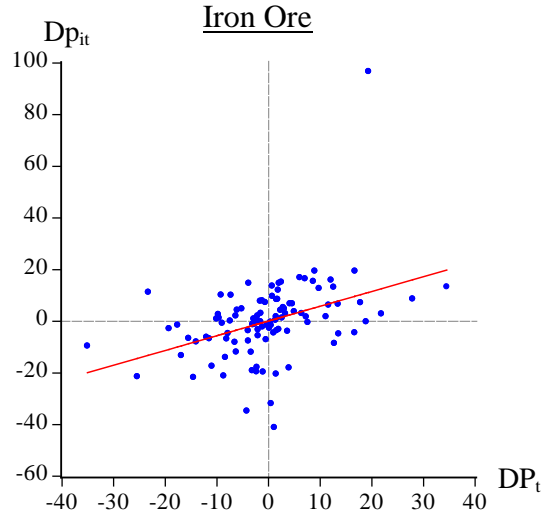
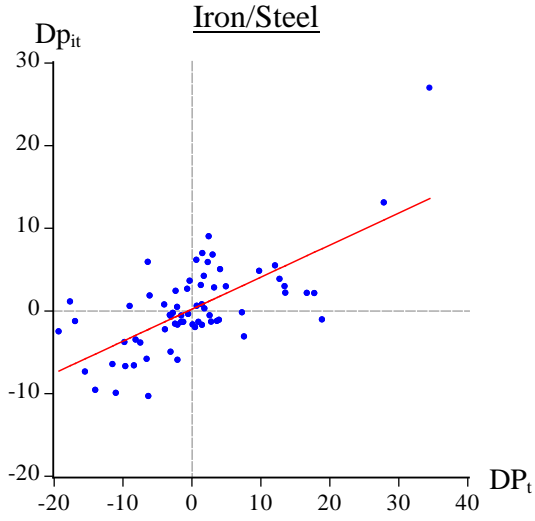
FIGURE 2.4
SCATTER PLOTS OF RELATIVE PRICES, 21 METALS, 1900-2007



(Figure continues on next page.)

FIGURE 2.4 (CONTINUED)

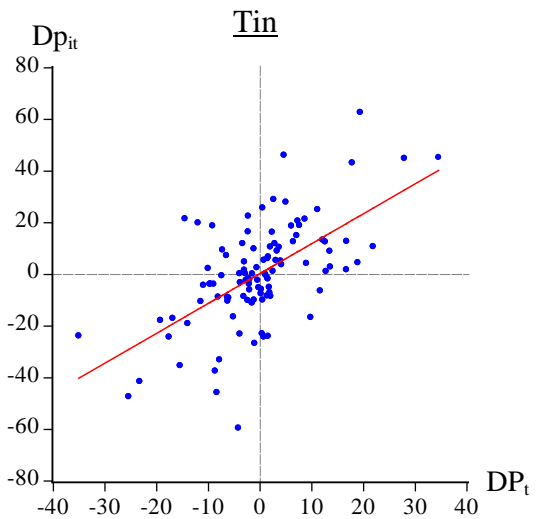
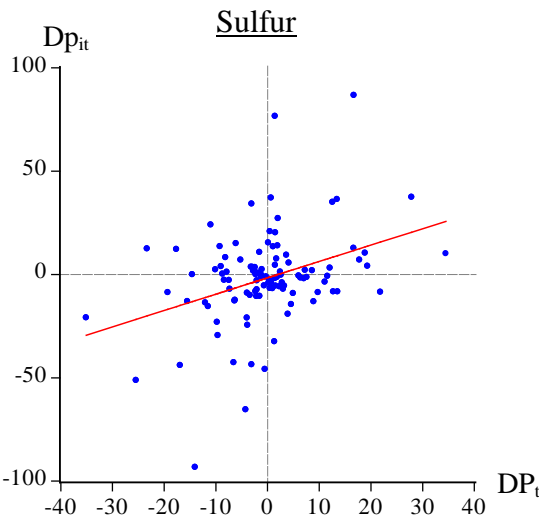
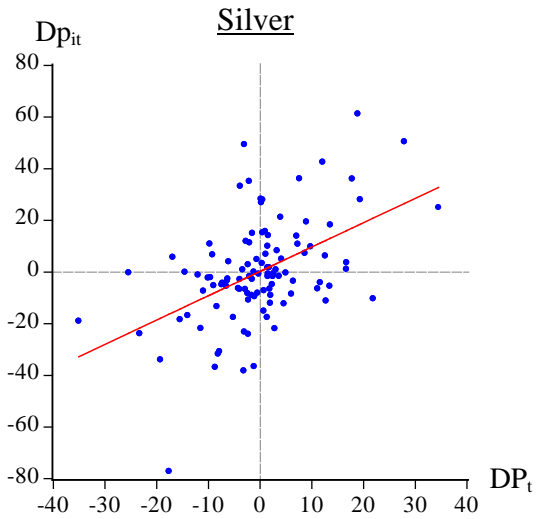
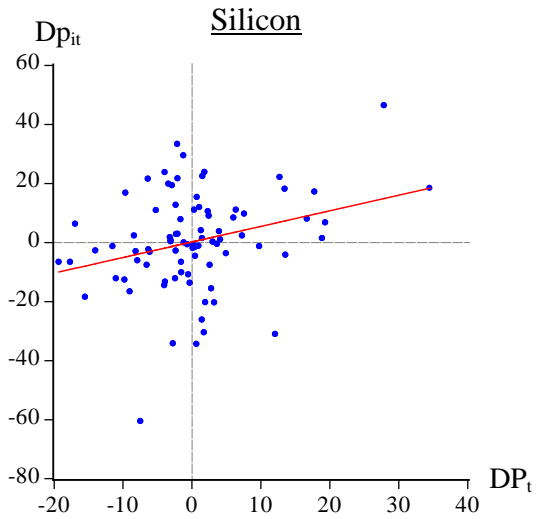
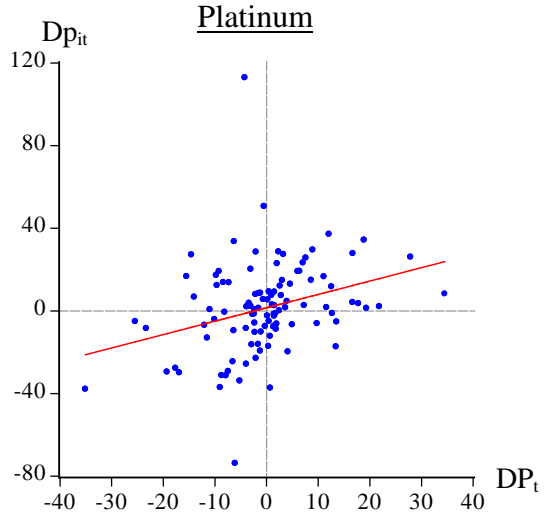
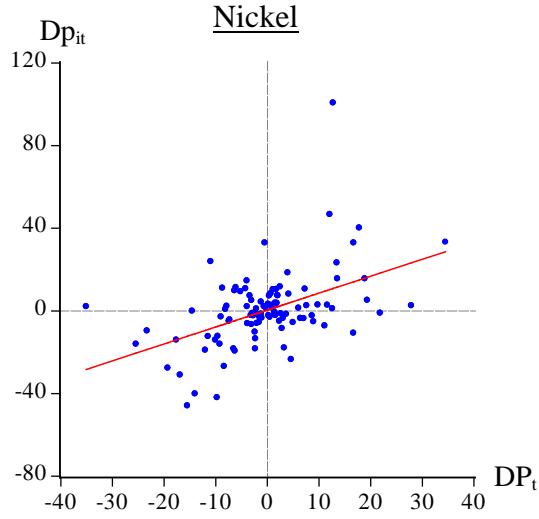
SCATTER PLOTS OF RELATIVE PRICES, 21 METALS, 1900-2007



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FIGURE 2.4 (CONTINUED)

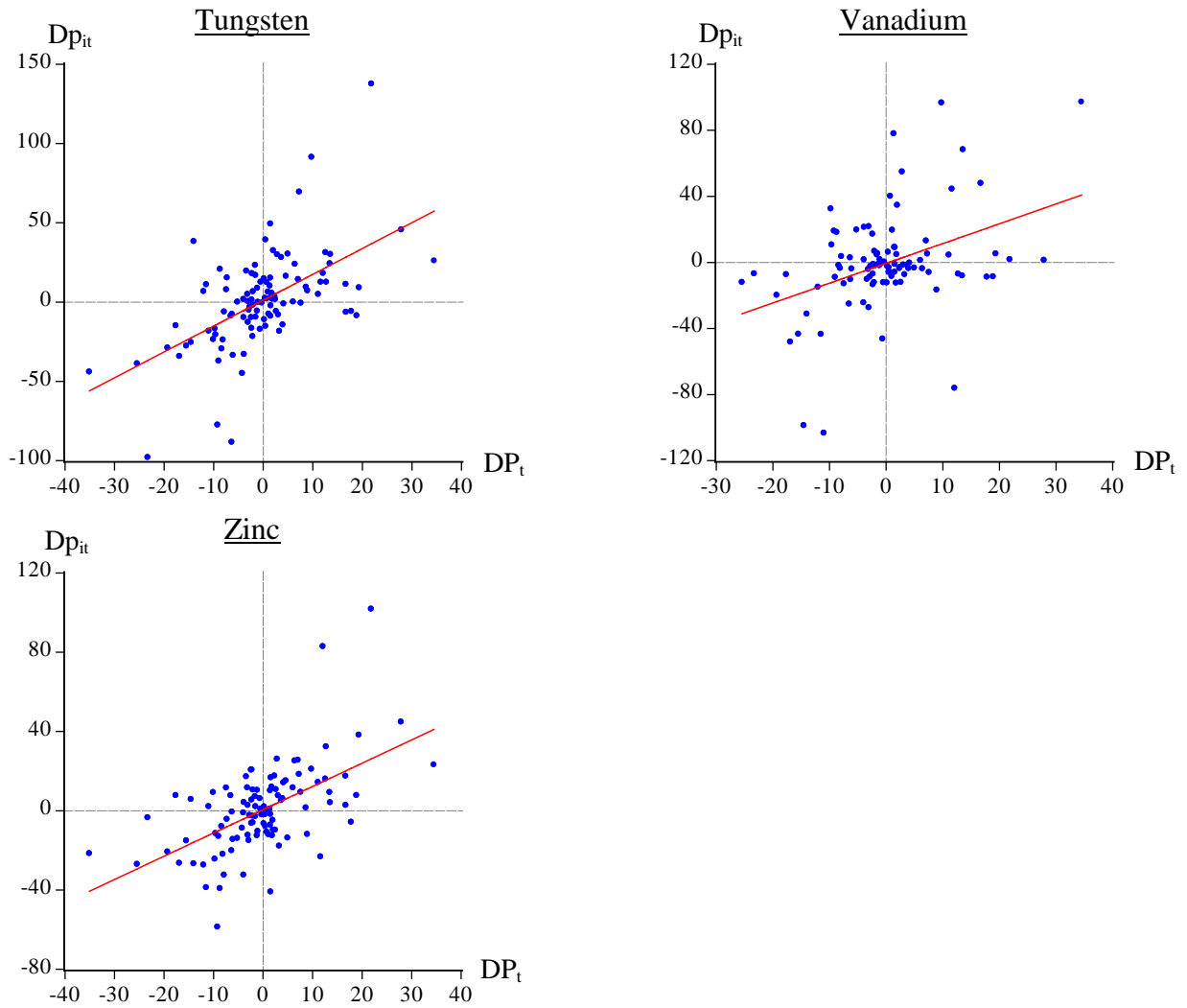
SCATTER PLOTS OF RELATIVE PRICES, 21 METALS, 1900-2007



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FIGURE 2.4 (CONTINUED)

SCATTER PLOTS OF RELATIVE PRICES, 21 METALS, 1900-2007



Notes: The prices in these scatters are logarithmic changes $\times 100$.

TABLE 2.3
DECOMPOSITION OF METALS PRICE VOLATILITY, 21 METALS, 1900-2007

Metal	A. Linear model				B. Quadratic model				
	Intercept α_i	Slope β_i	Factor component (%)		Intercept α'_i	Linear term β'_i	Quadratic term γ_i	Factor component (%)	
			Global	Commodity-specific				Global	Commodity-specific
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Boron	-0.97 (2.54)	0.16 (0.25)	0.42	99.58	-2.04 (2.86)	0.16 (0.25)	0.01 (0.01)	1.05	98.95
2. Iron/Steel	0.22 (0.50)	0.39 (0.05)	46.59	53.41	-0.43 (0.55)	0.32 (0.06)	0.01 (0.00)	51.10	48.90
3. Silicon	0.19 (1.74)	0.53 (0.19)	8.48	91.52	-0.70 (1.96)	0.42 (0.22)	0.01 (0.01)	9.55	90.45
4. Gold	0.47 (1.25)	0.54 (0.12)	15.96	84.04	-0.12 (1.41)	0.53 (0.12)	0.01 (0.01)	16.52	83.48
5. Iron ore	0.13 (1.31)	0.57 (0.13)	16.15	83.85	-0.62 (1.48)	0.57 (0.13)	0.01 (0.01)	17.03	82.97
6. Platinum	1.53 (2.04)	0.65 (0.20)	9.30	90.70	2.34 (2.30)	0.65 (0.20)	-0.01 (0.01)	9.77	90.23
7. Chromium	0.49 (1.91)	0.78 (0.19)	14.46	85.54	0.44 (2.16)	0.78 (0.19)	0.00 (0.01)	14.45	85.55
8. Sulfur	-1.62 (2.05)	0.80 (0.20)	13.27	86.73	-1.57 (2.32)	0.79 (0.20)	0.00 (0.01)	13.17	86.83
9. Magnesium	-3.92 (1.50)	0.80 (0.15)	23.07	76.93	-5.44 (1.68)	0.73 (0.16)	0.02 (0.01)	26.00	74.00
10. Nickel	0.45 (1.51)	0.82 (0.15)	23.07	76.93	-0.03 (1.71)	0.82 (0.15)	0.00 (0.01)	23.17	76.83
11. Lead	0.26 (1.46)	0.90 (0.14)	27.48	72.52	-0.09 (1.65)	0.89 (0.14)	0.00 (0.01)	27.64	72.36
12. Manganese	0.86 (1.99)	0.93 (0.19)	18.14	81.86	0.26 (2.24)	0.92 (0.19)	0.01 (0.01)	18.35	81.65
13. Silver	0.28 (1.68)	0.95 (0.16)	24.30	75.70	-0.21 (1.91)	0.94 (0.16)	0.00 (0.01)	24.31	75.69
14. Aluminium	-1.57 (1.35)	1.06 (0.13)	38.42	61.58	-1.33 (1.52)	1.06 (0.13)	0.00 (0.01)	38.83	61.17
15. Tin	0.40 (1.53)	1.16 (0.15)	36.95	63.05	-0.13 (1.72)	1.15 (0.15)	0.00 (0.01)	37.11	62.89
16. Zinc	0.54 (1.73)	1.17 (0.17)	31.62	68.38	-0.69 (1.93)	1.16 (0.17)	0.01 (0.01)	33.25	66.75
17. Vanadium	-0.58 (2.78)	1.21 (0.28)	16.15	83.85	-0.77 (3.20)	1.19 (0.29)	0.00 (0.02)	16.07	83.93
18. Copper	0.04 (1.33)	1.21 (0.13)	45.40	54.60	0.41 (1.50)	1.21 (0.13)	0.00 (0.01)	45.55	54.45
19. Tungsten	1.20 (2.39)	1.63 (0.23)	31.91	68.09	2.12 (2.69)	1.64 (0.23)	-0.01 (0.01)	32.61	67.39
20. Molybdenum	1.97 (3.44)	1.96 (0.35)	25.31	74.69	2.08 (3.95)	1.96 (0.36)	0.00 (0.02)	25.32	74.68
21. Cobalt	-0.28 (4.06)	2.54 (0.39)	28.27	71.73	4.79 (4.46)	2.57 (0.38)	-0.05 (0.02)	32.25	67.75
Mean			23.56	76.44				24.43	75.57

Note: Standard errors are in parentheses.

FIGURE 2.5

SHARE OF GLOBAL RISK COMPONENT, 21 METALS

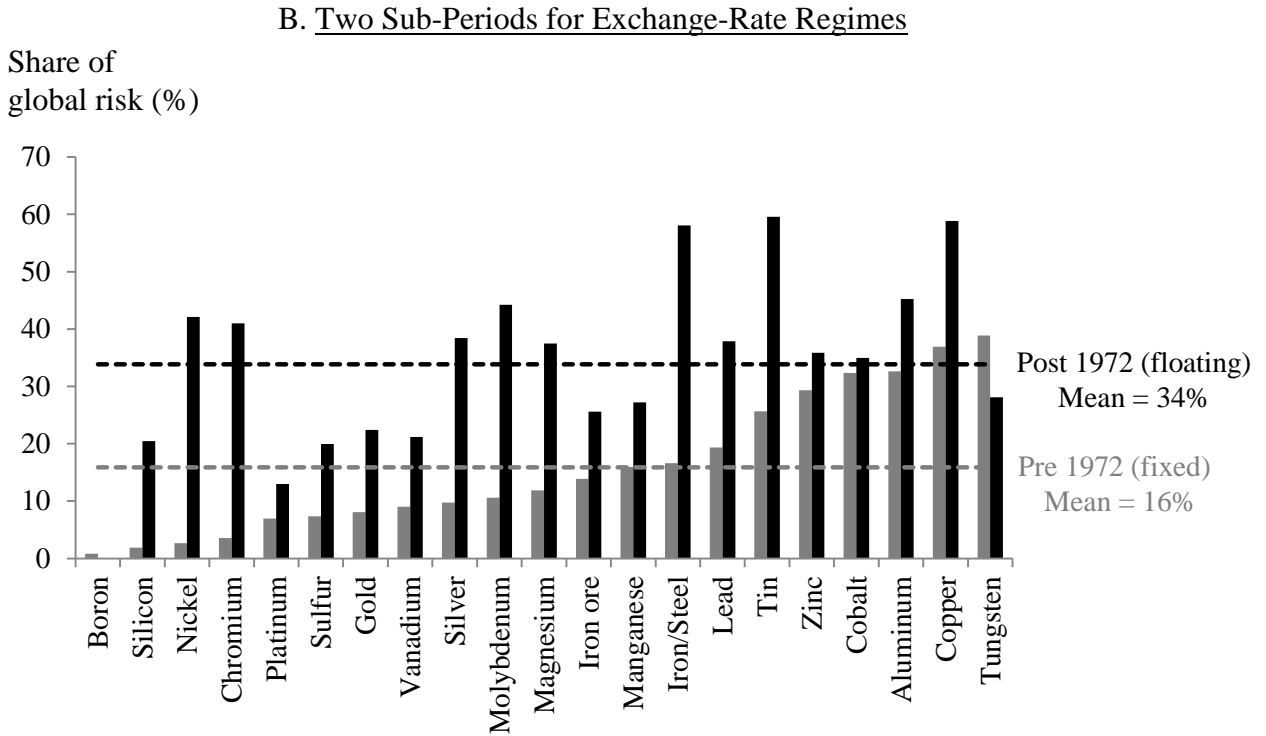
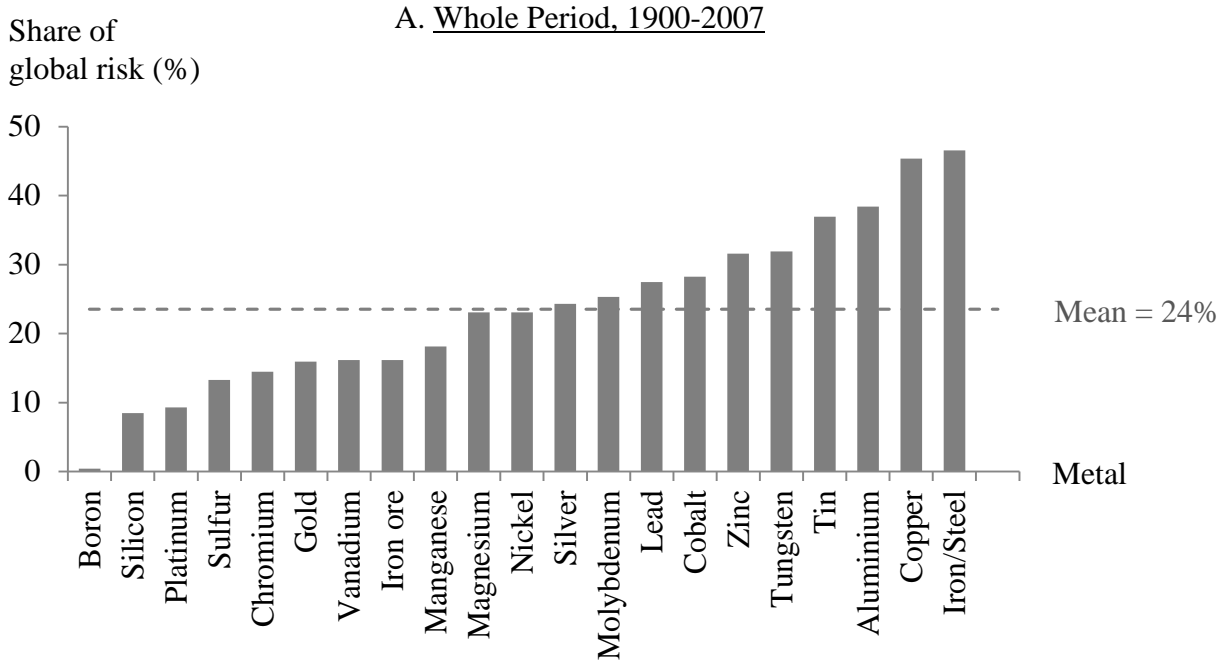


TABLE 2.4

COMPONENTS OF METALS PRICE VOLATILITY, 21 METALS, TWO EXCHANGE-RATE REGIMES

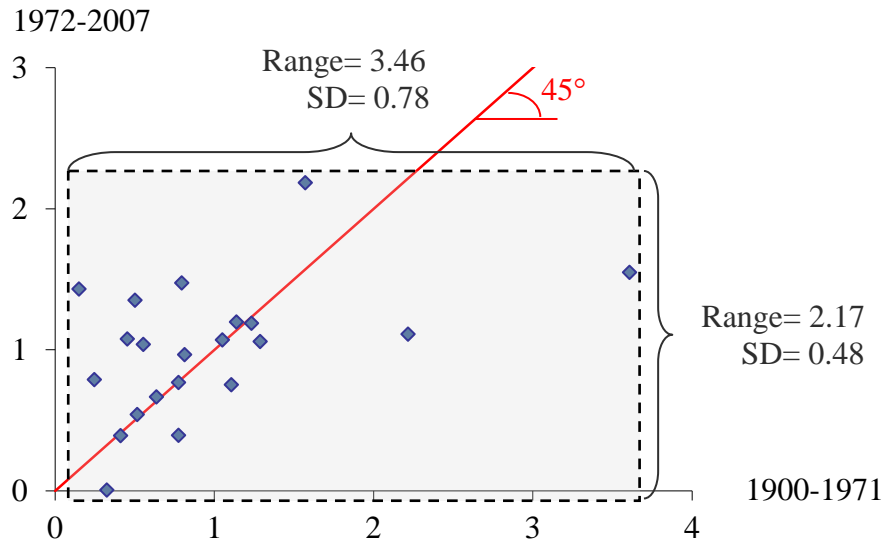
Metal	1900-1971 (Fixed)				1972-2007 (Floating)				
	Slope β_i	DW	Factor component (%)		Slope β_i	DW	Factor component (%)		β_i rank
			Global	Commodity-specific			Global	Commodity-specific	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Nickel	0.15 (0.11)	1.44	2.68	97.32	1.43 (0.29)	1.98	42.08	57.92	18
2. Gold	0.25 (0.10)	1.39	8.06	91.94	0.79 (0.25)	1.62	22.41	77.59	8
3. Boron	0.33 (0.43)	2.36	0.81	99.19	0.01 (0.10)	1.83	0.01	99.99	1
4. Iron/Steel	0.41 (0.19)	0.69	13.89	86.11	0.39 (0.06)	2.16	58.07	41.93	3
5. Chromium	0.45 (0.28)	1.78	3.56	96.44	1.08 (0.22)	2.44	40.97	59.03	13
6. Silver	0.50 (0.18)	1.78	9.74	90.26	1.35 (0.29)	2.04	38.44	61.56	17
7. Silicon	0.52 (0.55)	2.17	1.88	98.12	0.54 (0.18)	2.51	20.43	79.57	4
8. Sulfur	0.55 (0.24)	1.35	7.33	92.67	1.04 (0.36)	1.82	19.96	80.04	10
9. Platinum	0.64 (0.28)	1.51	6.97	93.03	0.67 (0.30)	1.90	12.97	87.03	5
10. Iron ore	0.78 (0.21)	2.82	16.60	83.40	0.39 (0.12)	1.42	25.57	74.43	2
11. Magnesium	0.78 (0.29)	1.31	11.86	88.14	0.77 (0.17)	1.93	37.47	62.53	7
12. Vanadium	0.80 (0.33)	1.60	9.01	90.99	1.47 (0.49)	2.05	21.15	78.85	19
13. Lead	0.81 (0.20)	2.00	19.33	80.67	0.97 (0.21)	2.15	37.84	62.16	9
14. Aluminium	1.05 (0.18)	1.88	32.61	67.39	1.07 (0.20)	2.17	45.24	54.76	12
15. Manganese	1.11 (0.31)	2.49	15.94	84.06	0.75 (0.21)	2.24	27.18	72.82	6
16. Tin	1.14 (0.23)	1.62	25.66	74.34	1.20 (0.17)	2.18	59.59	40.41	16
17. Copper	1.23 (0.19)	2.00	36.93	63.07	1.19 (0.17)	1.81	58.82	41.18	15
18. Zinc	1.29 (0.24)	2.13	29.32	70.68	1.06 (0.24)	2.03	35.85	64.15	11
19. Molybdenum	1.57 (0.60)	2.91	10.60	89.40	2.18 (0.42)	1.83	44.24	55.76	21
20. Tungsten	2.22 (0.33)	2.18	38.87	61.13	1.11 (0.30)	1.95	28.09	71.91	14
21. Cobalt	3.61 (0.63)	2.13	32.36	67.64	1.55 (0.36)	1.59	34.98	65.02	20
Mean			15.91	84.09			33.88	66.12	

Note: Standard errors are in parentheses.

FIGURE 2.6

RISK OF METAL PRICES, TWO EXCHANGE-RATE REGIMES

A. Slope Coefficient, β_i



B. Global Risk Component, R^2 (%)

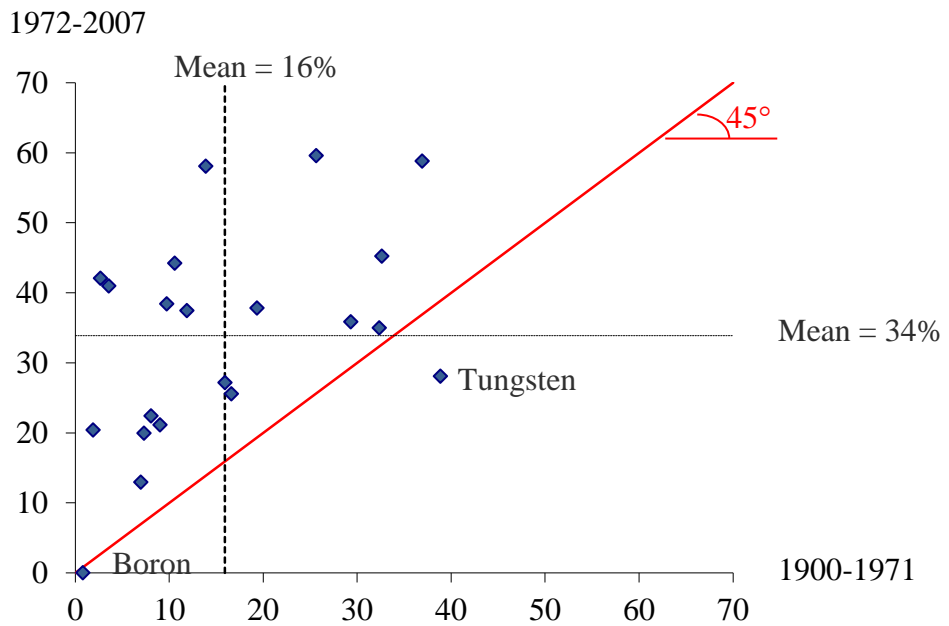
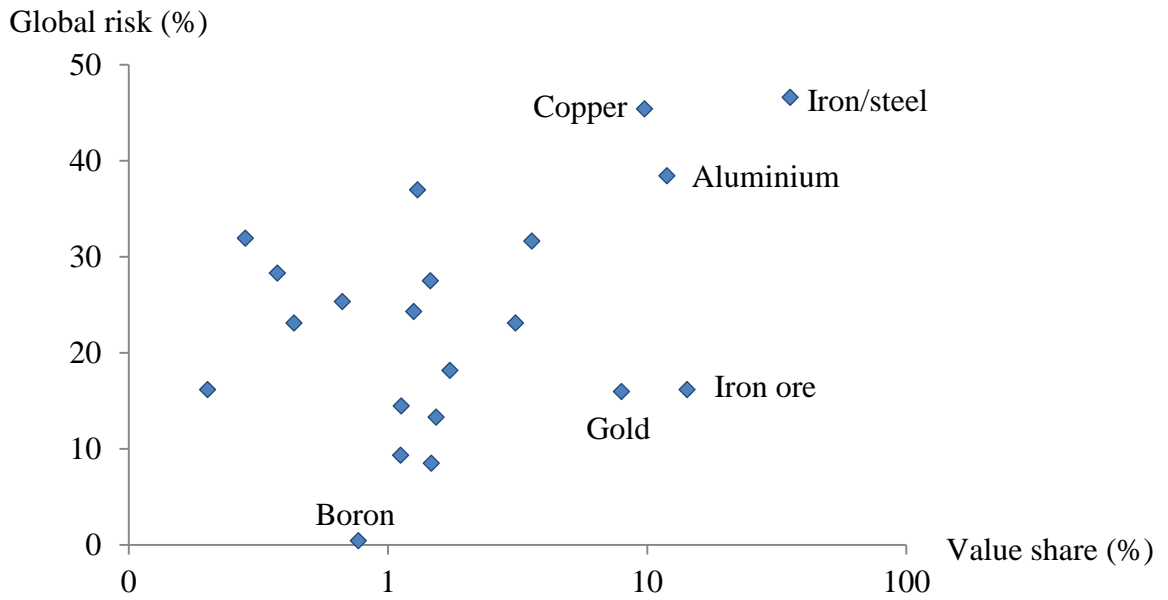


FIGURE 2.7
ECONOMIC IMPORTANCE
AND GLOBAL RISK COMPONENT, 21 METALS



Note: The horizontal axis is on a log scale and refers to the value shares of the 21 metals, averaged over 1964-2007; the vertical axis refers to the R^2 's from column 4 of Table 2.3.

TABLE 3.1
COMPARISON OF AVERAGE METAL VALUES, 1950–2010
(Logarithmic differences ×100)

Metal	Metal																Row average
	Iron ore	Aluminium	Copper	Gold	Zinc	Nickel	Manganese	Lead	Sulfur	Tin	Silver	Chromium	Platinum	Molybdenum	Magnesium	Cobalt	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
1. Iron ore		31	39	72	140	172	206	219	241	245	253	276	298	334	357	379	204
2. Aluminium			8	41	109	141	175	188	211	214	222	246	268	304	326	348	173
3. Copper				32	101	133	167	180	202	205	214	237	259	295	318	340	165
4. Gold					68	100	135	147	170	173	181	205	227	263	285	307	132
5. Zinc						32	66	79	101	105	113	137	159	195	217	239	64
6. Nickel							34	47	70	73	81	105	127	163	185	207	32
7. Manganese								13	35	38	47	70	92	128	150	173	-2
8. Lead									22	26	34	57	80	115	138	160	-15
9. Sulfur										3	12	35	57	93	115	138	-37
10. Tin											8	32	54	90	112	134	-41
11. Silver												23	46	81	104	126	-49
12. Chromium													22	58	80	103	-72
13. Platinum														36	58	80	-95
14. Molybdenum															22	45	-130
15. Magnesium																22	-153
16. Cobalt																	-175
Column average	204	173	165	132	64	32	-2	-15	-37	-41	-49	-72	-95	-130	-153	-175	0

FIGURE 3.1
DIFFERENCES IN AVERAGE METAL VALUES, 1950–2010
(Logarithmic deviations from the mean $\times 100$)

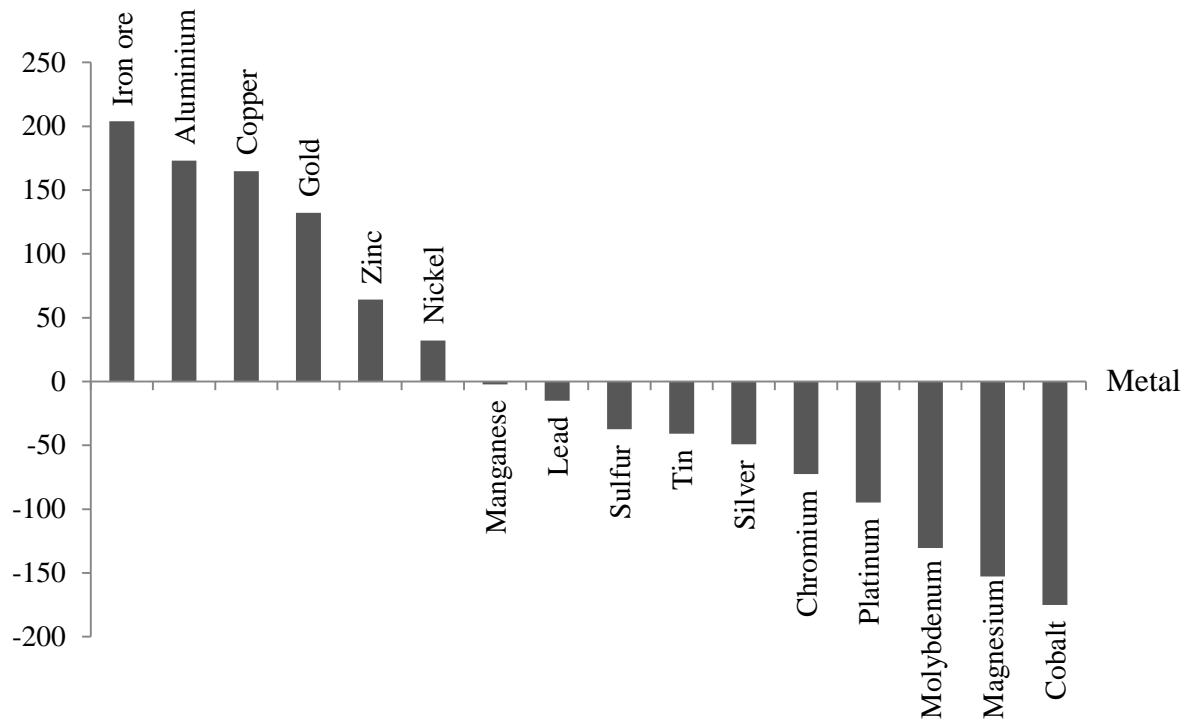


TABLE 3.2
SUMMARY OF AVERAGE VALUES, PRICES AND VOLUMES COMPARISONS, 1950–2010
(Logarithmic differences $\times 100$)

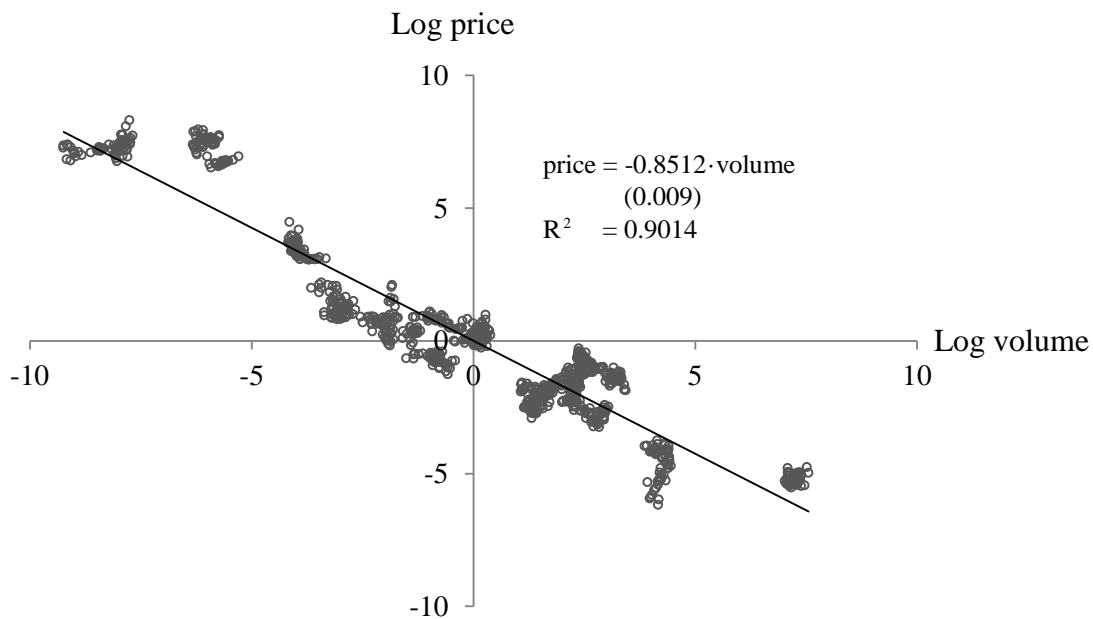
Decade	Metal																S.D.
	Iron ore	Aluminium	Copper	Gold	Zinc	Nickel	Manganese	Lead	Sulfur	Tin	Silver	Chromium	Platinum	Molybdenum	Magnesium	Cobalt	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
<u>A. Values</u>																	
1950–59	205	142	176	123	88	-11	28	71	-2	26	-51	-115	-193	-153	-157	-175	126
1960–69	226	178	182	102	75	24	2	30	5	9	-53	-129	-145	-128	-157	-220	128
1970–79	211	174	169	93	63	45	-22	-4	-18	-6	-48	-88	-104	-101	-169	-195	116
1980–89	199	171	126	158	45	15	-16	-65	22	-49	-21	-57	-64	-156	-143	-163	111
1990–99	180	188	162	172	65	41	1	-54	-71	-97	-66	-32	-42	-164	-137	-146	118
2000–10	201	186	173	145	50	74	-6	-63	-149	-119	-55	-19	-26	-85	-154	-154	121
Average	204	173	165	132	64	32	-2	-15	-37	-41	-49	-72	-95	-130	-153	-175	115
<u>B. Prices</u>																	
1950–59	-522	-97	-69	678	-152	8	-264	-139	-405	56	309	-258	717	70	-64	130	329
1960–69	-505	-97	-63	669	-160	23	-289	-163	-408	75	337	-253	715	88	-60	90	329
1970–79	-515	-128	-74	707	-162	29	-296	-180	-458	89	363	-222	713	92	-75	118	342
1980–89	-513	-141	-117	771	-178	1	-268	-223	-414	74	378	-207	734	38	-62	128	351
1990–99	-534	-138	-96	755	-158	13	-224	-189	-496	35	326	-192	742	23	-53	186	351
2000–10	-525	-149	-86	756	-171	48	-227	-176	-556	21	344	-180	754	102	-88	134	358
Average	-519	-126	-84	723	-164	21	-260	-178	-458	57	343	-218	730	69	-67	131	343
<u>C. Volumes</u>																	
1950–59	727	238	244	-556	240	-19	291	210	403	-30	-359	142	-910	-223	-93	-306	390
1960–69	731	275	244	-567	235	1	291	192	413	-66	-390	124	-860	-217	-97	-310	387
1970–79	725	302	243	-614	226	17	273	176	440	-94	-412	135	-818	-193	-94	-313	388
1980–89	712	312	243	-613	223	14	252	157	435	-123	-399	149	-798	-194	-81	-290	382
1990–99	715	326	258	-583	223	28	225	135	425	-132	-392	160	-784	-186	-84	-332	378
2000–10	726	335	258	-611	221	27	221	114	407	-140	-400	161	-780	-186	-66	-288	379
Average	723	299	249	-591	228	11	258	163	420	-98	-392	146	-824	-200	-86	-306	383

FIGURE 3.2

RELATIVE PRICES AND VOLUMES OF 16 METALS, 1950–2010

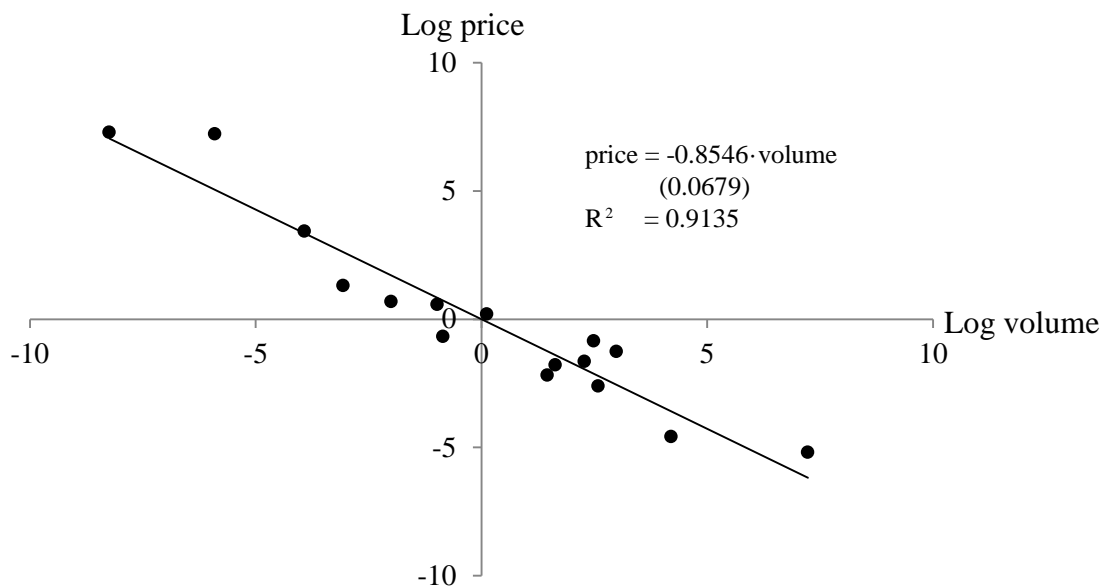
A. Observations across Time and Metals

($nT = 16 \times 61 = 976$)



B. Observations across Metals

($n = 16$)



Notes: Panel A is a scatter plot of prices against volumes for 16 metals in each of 61 years, with both variables measured as logarithmic differences from the means (*not* $\times 100$ here). In Panel B, the 16 points represent averages over the 61 years of the relative price and volume of 16 metals. Standard errors are in parentheses.

TABLE 3.3
PRICE FLEXIBILITY FOR METALS

$$x_{i,t}^p = \beta_t x_{i,t}^q + \varepsilon_{it}, i = 1, \dots, 16$$

Period	Price flexibility β	R^2
(1)	(2)	(3)
<u>A. Average by decade</u>		
1950–59	-0.80	0.91
1960–69	-0.81	0.90
1970–79	-0.84	0.91
1980–89	-0.88	0.91
1990–99	-0.88	0.90
2000–10	-0.90	0.89
<u>B. Summary statistics over 1950–2010</u>		
Mean	-0.85	0.90
Median	-0.86	0.90
Minimum	-0.94	0.87
Maximum	-0.77	0.94

Notes: The regression equation given at the top of the table is estimated separately for each year. Panel A gives the decade averages of the estimated slope coefficients and R^2 values, while panel B summarises the 61 estimates of the slopes and R^2 values. For estimates when the data are pooled over the 61 years, see Figure 3.2.

TABLE 3.4
PRICE FLEXIBILITY FOR METALS
AND METAL-SPECIFIC INTERCEPTS, 1950–2010

$$x_{i,t}^p = \alpha_i + \beta x_{i,t}^q + \varepsilon_{it}, i = 1, \dots, 16, t = 1, \dots, 61$$

Variable (1)	Coefficient (2)	
Volume, β	-0.07	(0.04)
Intercept α_i		
Aluminium	-1.03	(0.13)
Chromium	-2.07	(0.08)
Cobalt	1.08	(0.14)
Copper	-0.65	(0.11)
Gold	6.79	(0.25)
Iron ore	-4.65	(0.31)
Lead	-1.66	(0.08)
Magnesium	-0.74	(0.06)
Manganese	-2.41	(0.12)
Molybdenum	0.54	(0.10)
Nickel	0.22	(0.04)
Platinum	6.68	(0.35)
Silver	3.14	(0.17)
Sulfur	-4.26	(0.18)
Tin	0.50	(0.06)
Zinc	-1.47	(0.11)
R^2	0.99	

Note: Standard errors are in parentheses.

TABLE 3.5
PANEL UNIT ROOT TESTS, 16 METAL PRICES, 1950-2010

Test statistic (1)	Relative price		Relative volumes		Residuals	
	Statistic (2)	p-value (3)	Statistic (4)	p-value (5)	Statistic (6)	p-value (7)
<u>Null: Common unit root process</u>						
Levin, Lin and Chu - t^*	-2.797	0.0026	-4.218	0.0000	-3.636	0.0001
<u>Null: Individual unit root processes</u>						
Im, Pesaran and Shin - W	-3.586	0.0002	-2.655	0.0040	-4.130	0.0000
ADF - χ^2	69.118	0.0002	61.025	0.0015	74.474	0.0000
Phillips-Perron - χ^2	62.700	0.0009	83.038	0.0000	74.233	0.0000

Notes: 1. For all tests, the optimal lag length is selected on the basis of the SIC, and an individual constant is included. The Bartlett kernel is used for the Levin, Lin and Chu test.

2. Columns 6 and 7 refer to the residuals from equation (3.4) with the pooled OLS estimate of the slope.

TABLE 4.1
SUMMARY STATISTICS OF METAL PRICES, 1989/06-2012/04
(Monthly log-changes $\times 100$)

	Aluminium	Copper	Lead	Nickel	Tin	Zinc	Index
Mean	-0.17	0.23	0.22	-0.08	0.09	-0.15	0.06
Standard dev.	5.93	7.84	8.71	10.11	6.67	8.01	6.32
Maximum	15.45	26.50	24.83	31.06	23.60	24.14	18.44
Minimum	-24.77	-47.55	-32.40	-35.13	-21.48	-41.43	-35.51
JB statistic	20.69	376.22	20.13	12.66	15.99	79.79	179.09
Observations	274	274	274	274	274	274	269

Note: The JB (Jarque-Bera) statistic tests for normality.

TABLE 4.2
WEIGHTS OF SIX METALS
(Value shares, percentages)

Period	Aluminium	Copper	Lead	Nickel	Tin	Zinc
1990-1994	25.72	56.33	1.63	5.42	1.72	9.17
1995-1999	34.04	44.70	1.88	8.72	1.87	8.78
2000-2004	43.21	36.59	2.58	7.43	1.67	8.52
2005-2009	32.07	47.24	3.30	4.40	1.99	11.00
2010-2011	26.90	50.11	4.11	7.51	2.32	9.05
1990-2011	32.83	46.92	2.52	6.62	1.81	9.30

TABLE 4.3
CORRELATION COEFFICIENTS FOR METAL PRICES
(Log-changes of prices)

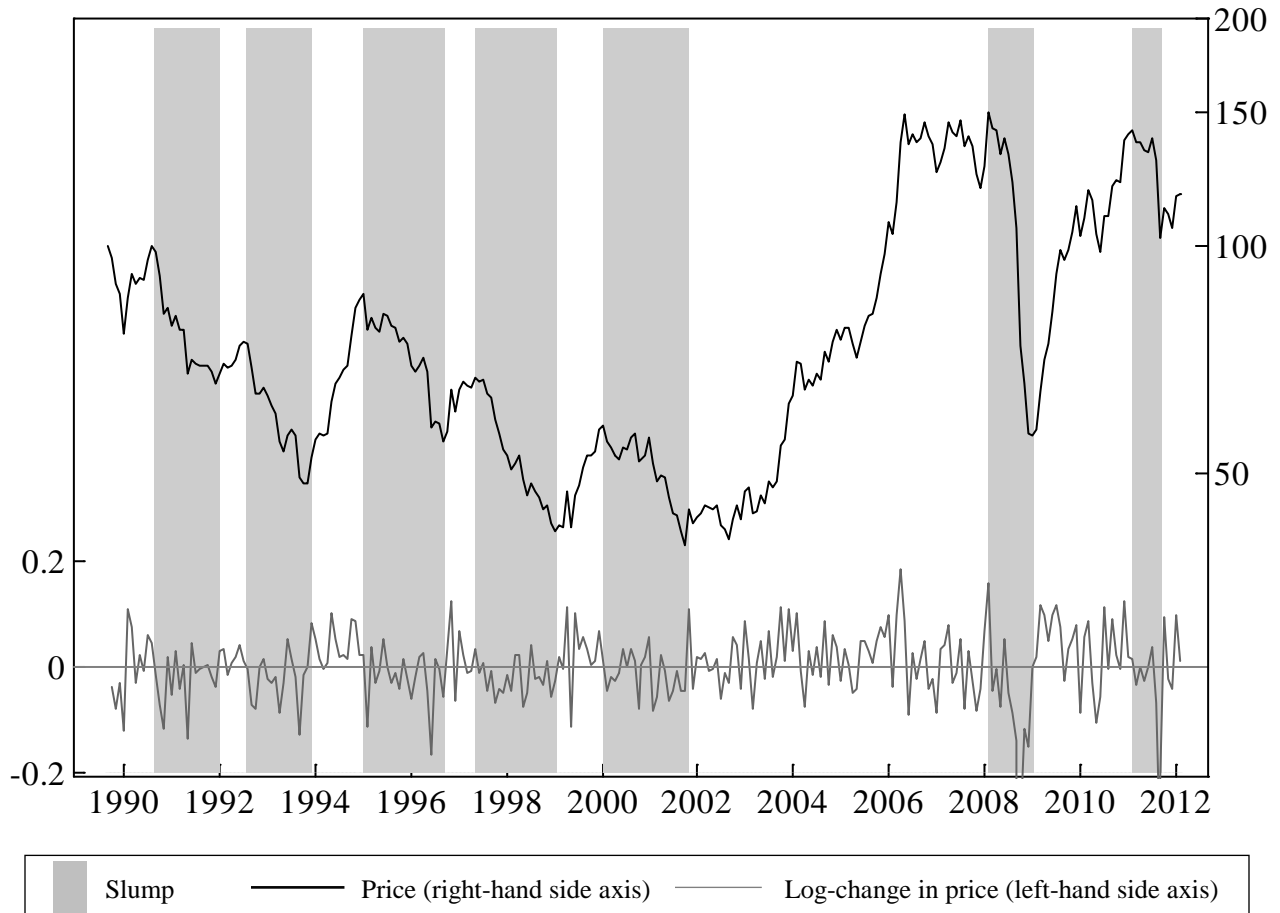
Metal	Aluminium	Copper	Lead	Nickel	Tin	Zinc	Index
Aluminium		0.64	0.39	0.50	0.49	0.49	0.82
Copper			0.45	0.51	0.47	0.59	0.94
Lead				0.39	0.38	0.54	0.54
Nickel					0.45	0.46	0.64
Tin						0.35	0.55
Zinc							0.70

TABLE 4.4
TURNING POINTS IN METAL PRICES

Episode	Price Index	Aluminium	Copper	Lead	Nickel	Tin	Zinc
<u>A. Peaks</u>							
1989/06-1991/12	1990/08	1990/09	1990/08	1990/06	1990/08	--	--
1991/12-1993/11	1992/07	1992/06	1992/07	1992/08	--	1992/06	1992/05
1993/11-1996/09	1995/01	1995/01	1994/12	1994/10 1996/05	1995/01	1995/06	1994/12
1996/09-1999/01	1997/05	1997/07	1997/05	--	--	--	1997/08
1999/01-2001/10	2000/01	2000/01	2000/09	1999/04 2001/02	2000/03	--	1999/12
2001/10-2009/01	2008/02	2008/02	2006/05 2008/06	2007/10	2003/12 2007/05	2004/05 2008/04	2006/11
2009/01-2011/09	2011/02	2011/04	2011/02	2009/12 2011/03	2011/02	2011/02	2009/12
2011/09-2012/04	--	--	--	--	--	--	--
<u>B. Troughs</u>							
1989/06-1990/08	--	1990/01	1990/01	1989/11	1990/01	--	--
1990/08-1992/07	1991/12	1991/11	1991/05	1992/01	--	1992/01	1991/10
1992/07-1995/01	1993/11	1993/11	1993/10	1993/09	1993/09	1993/09	1993/08
1995/01-1997/05	1996/09	1996/09	1996/09	1995/09	--	--	1996/09
1997/05-2000/01	1999/01	1999/02	1999/05	1998/10	1998/10	--	1998/12
2000/01-2008/02	2001/10	2002/09	2001/10 2007/01	2000/04 2002/09	2001/10 2005/10	2001/10 2005/11	2002/09
2008/02-2011/02	2009/01	2009/02	2008/12	2008/12 2010/06	2009/03	2009/03	2009/02 2010/06
2011/02-2012/04	2011/09	--	2011/09	--	2011/11	--	--

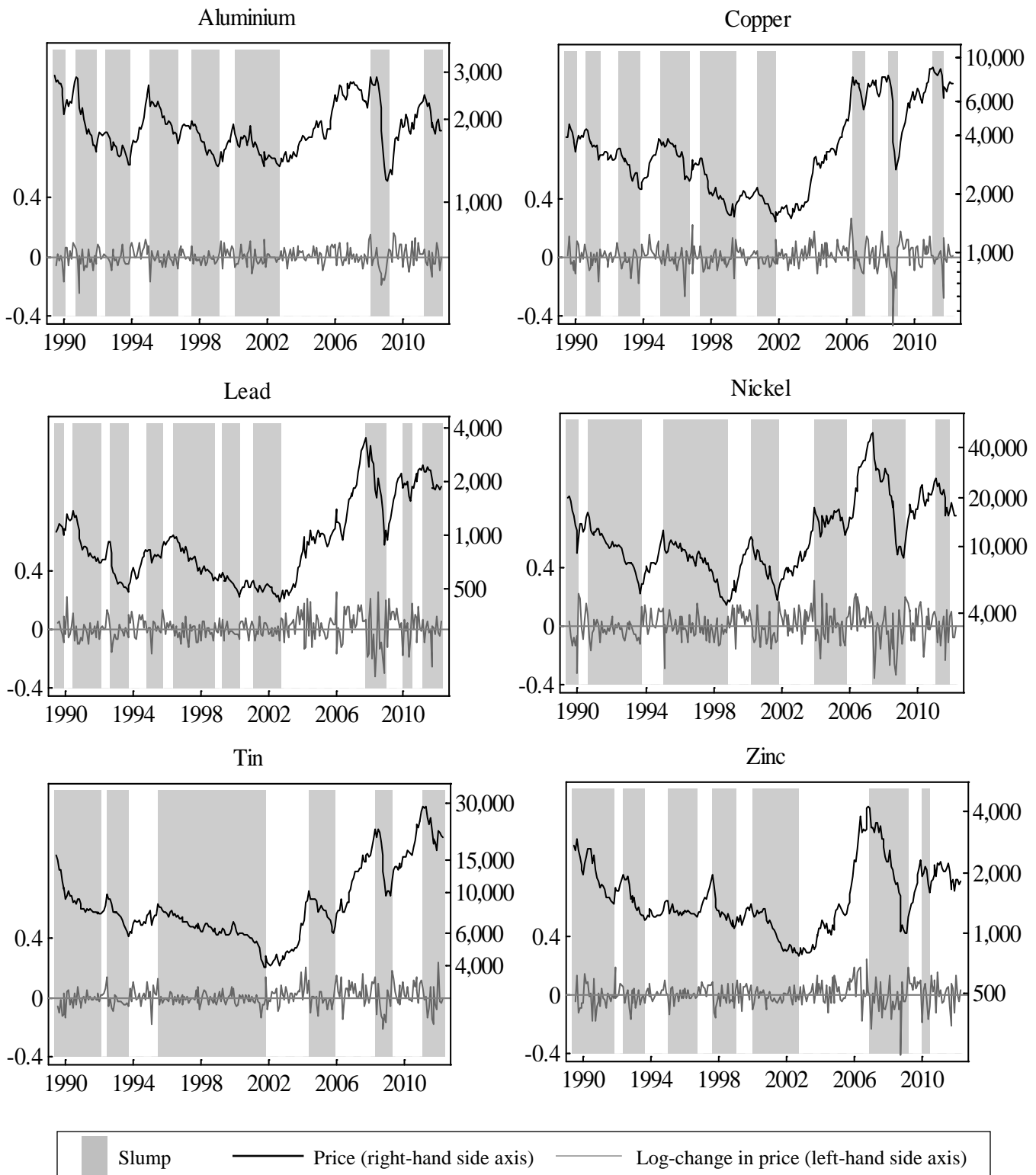
Note: An episode coincides with a complete cycle of the price index as determined by its turning points. In panel A, an episode is the trough-to-trough cycle; this period contains a peak in the index. In panel B, the cycle is defined in peak-to-peak terms; this cycle contains a trough in the index. These alternative definitions of the cycle represent two ways of dividing up the whole sample period into segments. As the sample period is fixed, the two sets of segments obviously overlap.

FIGURE 4.1
PRICE INDEX



Note: The dark line is the level of the price index (in terms \$US of 2005) with 1989M06 = 100. This index refers to the right-hand side axis (which is on a log scale). The grey line is the monthly log-change in the index, which refers to the left-hand axis. The shaded areas are the peak-to-trough slumps. The first shaded area is an open-ended slump as we are not present at its birth – that is, there is no peak observed prior to the first trough. The ticks on the horizontal axis refer to January of each year.

FIGURE 4.2
SIX METAL PRICES



Note: See note to Figure 4.1. The only difference is that here the prices are not indexes (and do not have any base year).

TABLE 4.5
SUMMARY OF PHASES IN METAL PRICES

Metal (1)	Slumps					Booms				
	No. of episodes (2)	Duration (No. of months) (3)	Log-change × 100			No. of episodes (7)	Duration (No. of months) (8)	Log-change × 100		
			Amplitude (4)	Monthly amplitude (5)	Excess index (6)			Amplitude (9)	Monthly amplitude (10)	Excess index (11)
Aluminium	7	19	-50.80	-3.21	-0.41	7	20	45.89	2.91	-1.10
Copper	8	13	-53.82	-5.51	-3.99	9	20	61.59	3.10	-0.25
Lead	9	15	-54.13	-3.89	0.90	9	15	58.01	4.02	-0.02
Nickel	6	26	-94.65	-4.23	-3.14	7	18	103.49	6.08	-1.43
Tin	5	30	-66.32	-3.75	-2.85	5	22	79.86	3.85	6.31
Zinc	6	20	-62.59	-3.61	1.90	7	18	64.94	4.17	5.44
Mean										
All	6.83	21	-63.72	-4.03	-1.27	7.33	19	68.96	4.02	1.49
No MB	5.33	22	-61.79	-3.89	-1.64	5.66	12	53.20	4.18	-1.45

Notes: Columns 3-6 and 8-11 are averages. The mean of the last row excludes the atypically long Millennium Boom (MB).

FIGURE 4.3
A TRIANGULAR MEASURE OF THE PRICE PATH

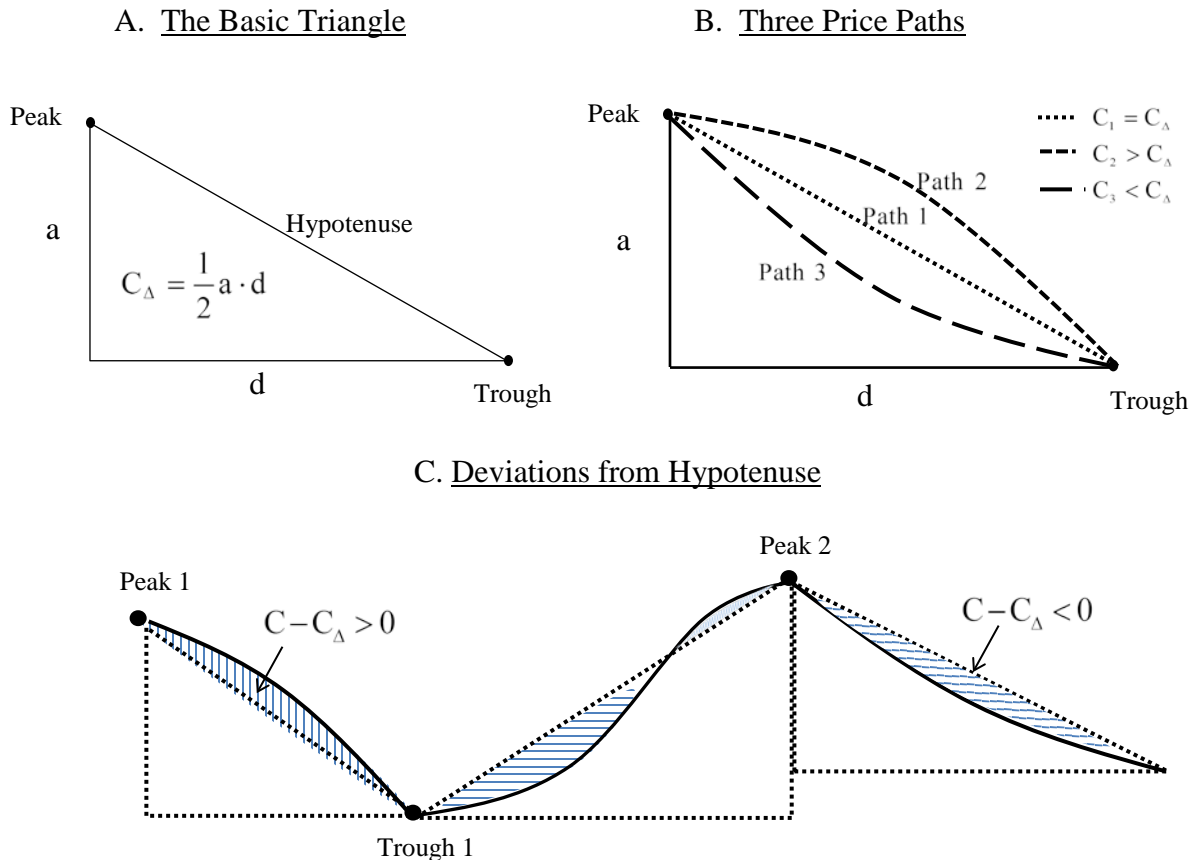
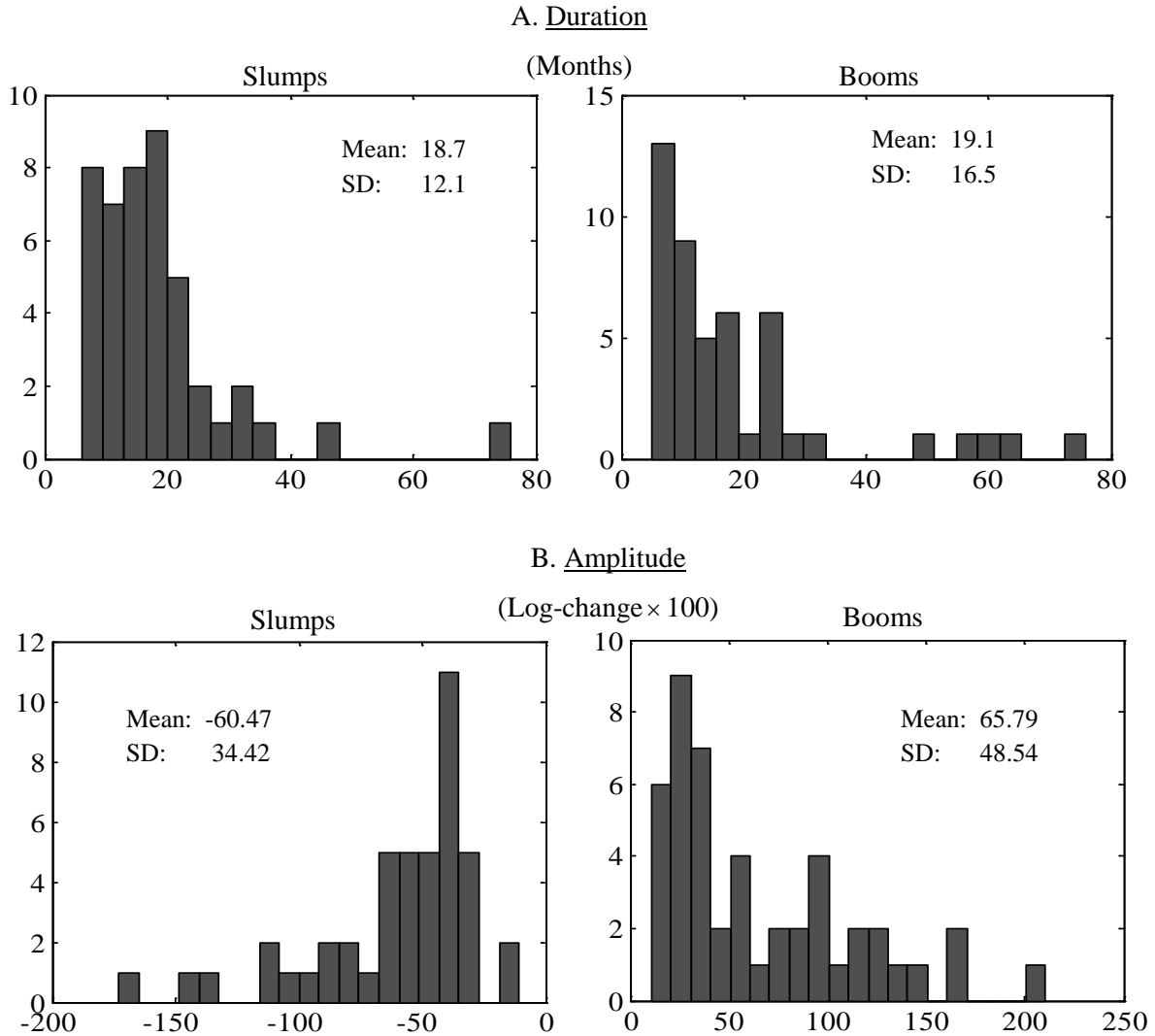


FIGURE 4.4
HISTOGRAMS OF DURATION AND AMPLITUDE

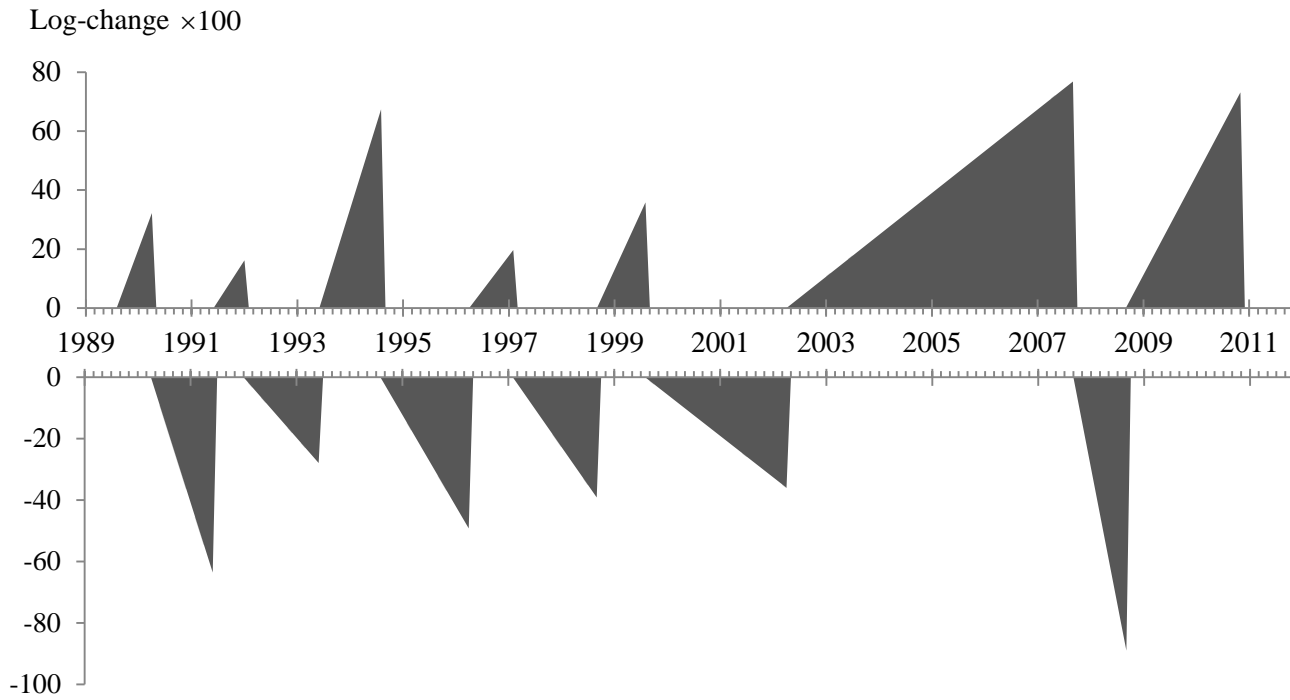


Note: As six metals have different numbers of episodes, the overall mean values here are not consistent with those in Table 4.5.

TABLE 4.6
CONCORDANCE INDEX FOR SIX METAL PRICES
(Percentages)

	Copper	Lead	Nickel	Tin	Zinc	Price index
Aluminium	79.27	75.27	72.36	73.82	81.45	88.89
Copper		65.45	69.09	69.09	70.18	85.56
Lead			65.09	68.73	70.55	71.11
Nickel				79.64	68.36	77.04
Tin					63.27	74.81
Zinc						75.93

FIGURE 4.5
DURATION AND AMPLITUDE OF BOOMS AND SLUMPS,
ALUMINIUM PRICES

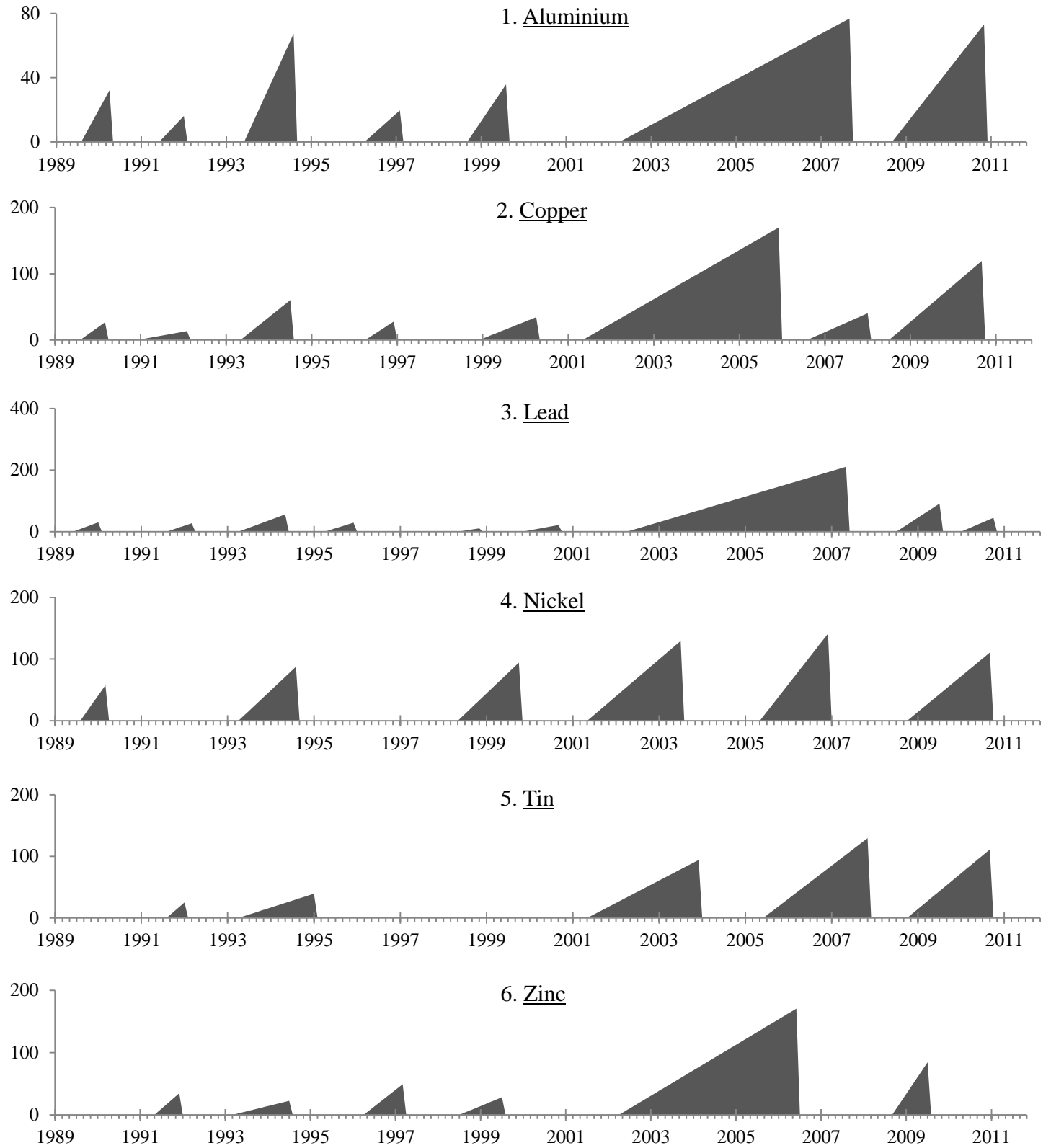


Note: The prominent ticks on the horizontal axis refer to June of each year.

FIGURE 4.6

DURATION AND AMPLITUDE OF BOOMS

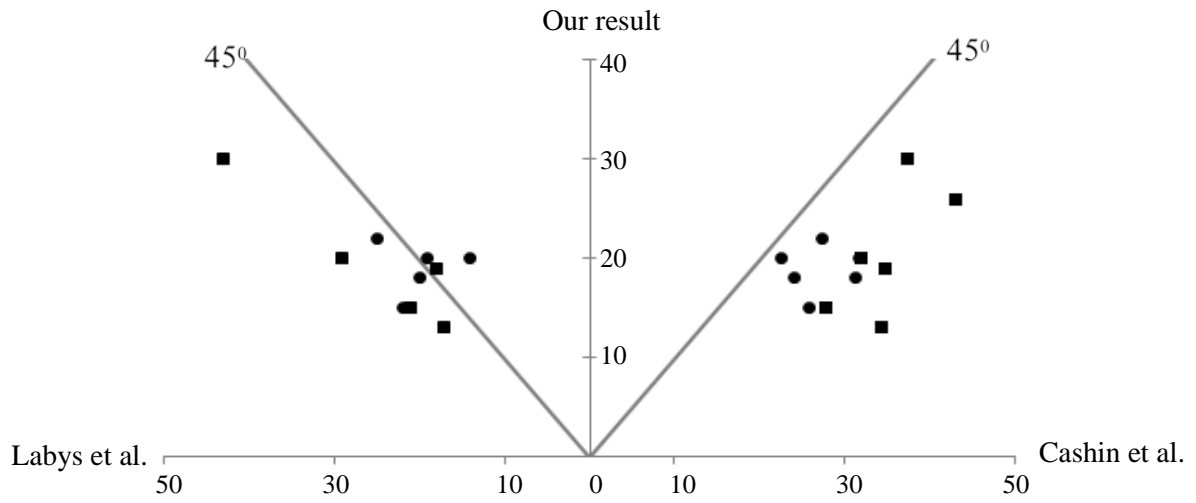
Log-change $\times 100$



Note: The prominent ticks on the horizontal axis refer to June of each year.

FIGURE 4.7
 THE CYCLICALITY OF METAL PRICES,
 COMPARISON OF RESULTS

A. Duration (months)



B. Amplitude (absolute log changes)

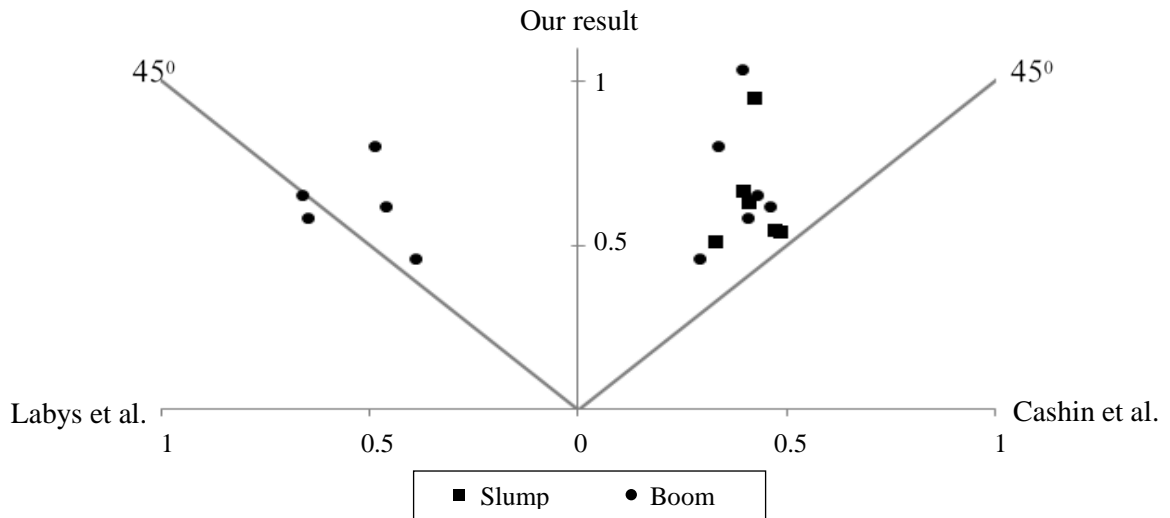


FIGURE 4.8

DNA TRIANGLES: THE PROPORTIONATE GROWTH CASE

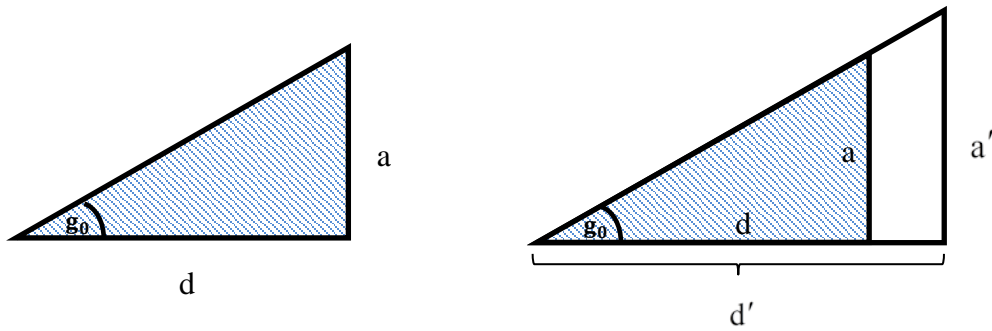


TABLE 4.7

DURATION, AMPLITUDE, GROWTH CORRELATION STRUCTURES

Scenario	DNA triangles	Correlation coefficient	
		Duration-amplitude ρ_{da}	Duration-growth ρ_{dg}
1. Amplitude and growth increase		> 0	> 0
2. Amplitude constant and growth falls		$= 0$	< 0
3. Amplitude and growth fall		< 0	< 0
4. Amplitude increases and growth constant		> 0	$= 0$

TABLE 4.8
MOMENTS OF DURATION AND AMPLITUDE, SIX METALS

Episode	Means			Standard deviations			Correlations		
	Duration D	Amplitude		Duration $\sqrt{V_d}$	Amplitude		Duration- amplitude ρ_{da}	Duration- growth ρ_{dg}	Amplitude- growth ρ_{ag}
		Total A	Per month G		Total $\sqrt{V_a}$	Per month $\sqrt{V_g}$			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
A. <u>Booms</u>									
1989/06 – 1991/12	7.25	36.77	5.11	0.43	12.22	1.82	-0.22	-0.34	0.99
1991/12 – 1993/11	8.00	23.37	3.43	3.10	7.68	1.58	-0.61	-0.84	0.90
1993/11 – 1996/09	15.67	55.60	3.70	2.62	20.62	1.51	-0.36	-0.60	0.96
1996/09 – 1999/01	9.67	32.24	3.31	1.25	12.44	1.03	0.55	0.21	0.93
1999/01 – 2001/10	13.20	42.90	3.10	2.79	26.20	1.29	0.75	0.57	0.97
2001/10 – 2009/01	46.50	149.7	3.84	16.83	41.50	1.88	0.09	-0.91	0.22
2009/01 – 2011/09	20.00	98.30	5.51	6.51	16.51	1.92	0.38	-0.96	-0.13
Mean	17.18	62.70	4.00	4.79	19.59	1.58	0.08	-0.41	0.69
B. <u>Slumps</u>									
1990/08 – 1992/07	14	-55.92	-4.06	4.08	13.39	0.42	-0.91	0.58	-0.20
1992/07 – 1995/01	18.67	-60.04	-3.34	8.28	25.93	0.99	-0.84	0.27	0.30
1995/01 – 1997/05	18.25	-32.25	-1.68	4.21	17.73	0.75	-0.66	-0.50	0.98
1997/05 – 2000/01	26.6	-67.14	-2.65	10.21	21.42	0.68	-0.86	0.47	0.04
2000/01 – 2008/02	30.83	-55.34	-2.38	21.83	21.42	1.25	-0.47	0.66	-0.31
2008/02 – 2011/02	15.33	-123.18	-9.42	7.06	31.80	4.25	-0.72	0.71	-0.16
Mean	20.61	-65.65	-3.92	9.28	21.95	1.39	-0.74	0.36	0.21

- Notes: 1. Units of columns 2 and 5 are months.
2. The elements of columns 3 are $100 \times \log(\text{peak price}/\text{trough price})$ for booms and the negative of this for slumps, that is, growth per episode.
3. The elements of columns 4 are $(100/\text{duration}) \times \log(\text{peak price}/\text{trough price})$ for booms and the negative of this for slumps, that is, growth per month.
4. Episodes in panel A are the dates of trough-to-trough cycles in the price index that contain peaks. Panel B episodes are peak-to-peak cycles containing troughs. See note to Table 4.4 for a more extensive discussion. The duration of a boom (slump) is then the period from the trough (peak) to the peak (trough).
5. As indicated in Table 4.4, in several episodes and for several metals, there are two turning points in the price trajectories. In such a case, we use the date corresponding to the largest increase or decrease in the price of the metal in question. An alternative approach is to average the two corresponding durations and amplitudes. This yields very similar results to the first approach.

TABLE 4.9
CROSS-AUTOCORRELATIONS OF CYCLES,
SIX METALS

Variable in previous episode (1)	Variable in current episode		
	Duration (2)	Amplitude (3)	Growth (4)
A. <u>Boom to slump</u>			
Duration	-0.156	-0.034	-0.317
Amplitude	-0.092	-0.663	-0.597
Growth	0.096	-0.681	-0.310
B. <u>Slump to boom</u>			
Duration	-0.236	0.406	0.639
Amplitude	0.389	-0.168	-0.420
Growth	0.096	0.227	0.255

Note: To understand this table, take, for example, the first entry of column 2, -0.156. This is the cross-metal correlation between the duration of the previous boom and the duration of the current slump, averaged over all boom to slump phases.

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11.19	Tyers, R. and Corbett, J.	JAPAN'S ECONOMIC SLOWDOWN AND ITS GLOBAL IMPLICATIONS: A REVIEW OF THE ECONOMIC MODELLING
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**ECONOMICS DISCUSSION PAPERS
2012**

DP NUMBER	AUTHORS	TITLE
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**ECONOMICS DISCUSSION PAPERS
2013**

DP NUMBER	AUTHORS	TITLE
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