ECONOMICS

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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. Regardless, this paper shows that the three facts are promising leads to understanding the evolution of world metal prices.

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1. INTRODUCTION

Droughts, China, biofuels, the value of the dollar and financial market uncertainty have all been held responsible for the volatility of commodity prices in recent times. Over much of history the story has been the same – commodity prices have been volatile with periods of dramatic booms and slumps with prices changing by as much as 50-80 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: 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. 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 cyclicality in particular.

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. Examples of global shocks are a slowing of growth in Chinese manufacturing and construction that substantially dampens world metals demand; and the Fed stopping/slowing quantitative easing, leading to a strengthening of the dollar and a slump in commodity prices. 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

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[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). A related question is 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).

view of the apparent common surges and slumps in prices that have occurred in recent times. This finding needs to be qualified, however, as we find 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. 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 (1977) Law". 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, 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, it is not possible to be hard and fast and, consequently, we 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 perennial questions, such as when a current boom/slump is about to peak/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 or if the trough is still some way off); if they should hedge 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 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 raises a substantial fraction of its revenue from royalty income.

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

2. GLOBAL SHOCKS DO NOT DOMINATE

This section examines the broad sweep of metals prices over the last century that leads to a simple split of prices into global and market-specific factors.[2] 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 2013 and production from 1964-2013 are from the US Geological Survey (USGS).[3] 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 importance of iron/steel and iron ore. Although in recent years iron/steel has declined in relative importance, it still accounts for 26 percent of the total in 2013. Over the 10 years to 2013, iron ore leapt from 12 to 27 percent of the total; much of this relative growth came at the expense of iron/steel.

Table 2.2 summarises the real price data.[4] Thus, for example, on average, platinum price grew by 1.2 percent a year over the 1900–2013 period, whereas magnesium prices decreased by 4 percent annually. It is evident (column 2) that there is substantial dispersion in prices.[5] The

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[2] This section is mostly an updated version of Chen (2010, 2012). For related research, see Bidarkota and Crucini (2000).

[3] 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/minerals/pubs/historical-statistics/>.

[4] Nominal prices are deflated by the US Consumer Price Index. Before 1913, we use the Cost-of-Living Index from Rees (1961, p. 74). After 1913, we use the CPI-U from the US Bureau of Labor Statistics, available from: <http://www.bls.gov> [8 January 2016]. One potential problem with using the CPI is quality change, which according to the Boskin Commission's best estimate, leads to an upward bias of 1.1 percent p.a. (Boskin et al., 1996). This induces a corresponding downward bias in the real prices of metals.

[5] Note that these are logarithmic changes, defined as $\mathrm{Dp}_{it} = \log p_{it} - \log p_{i,t-1}$. For small changes, $\mathrm{Dp}_{it} \approx \left[\left(p_{it} - p_{i,t-1} \right) / p_{i,t-1} \right]$, while the exact relationship is $e^{\mathrm{Dp}_{it}} - 1 = \left(p_{it} - p_{i,t-1} \right) / p_{i,t-1}$. Thus, for aluminium, for example,

volatility of returns is high with the standard deviation over the whole period ranging from a low of 7 percent p.a. for iron/steel to a high of 67 percent for sulfur (column 6 of Table 2.2). This large dispersion in prices dominates the small secular changes (column 2) in all cases. Conceivably, prices could be driven by common systematic factors, as well as market-specific factors. The last column of Table 2.2 shows that in almost all cases (except copper, lead and tin), price changes are not normally distributed (possibly because of large outliers).

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 $\mathrm{DP}_t = 1/21 \cdot \sum_{i=1}^{21} \mathrm{Dp}_{it}$, where $\mathrm{Dp}_{it} = \log p_{it} - \log p_{i,t-1}$ is the annual logarithmic change in the deflated price of metal i.[6]

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. 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.

We start by examining the mean and dispersion of the price changes, as in Figure 2.1. This reveals a tendency for the prices to move in synchronisation, so a common factor could be at play, at least to some degree. 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 1920s, the boom of the 1970s and again in the recent Millennium Boom. There is no "mechanical" reason for this "moment dependency" of prices, but it has also been observed in the early literature on inflation and relative price.[7] A further feature of the figure is the rather distinct price behaviour in three "epochs": 1900-1940, 1941-1970, and 1971-2013. The first and last epochs have relatively high price dispersion, while in the middle one there is much more

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the mean annual price change is $\mathrm{Dp}_i = -2.00$, the implied percentage change is $100 \times (e^{-2.00} - 1) = -87$ percent. In what follows, we describe log-changes multiplied by 100 as "percentage changes" on the understanding this is an approximation that holds better when the changes are modest (which is the case for the majority of the annual price changes).

[6] For the sub-period 1964-2013 when quantities are available, we computed a weighted index and found it to be reasonably close to its unweighted counterpart; the correlation between the two indexes is 0.97.

[7] See, for example, Balk (1978), Clements and Nguyen (1981), Foster (1978), Glejser (1965), Parks (1978) and Vining and Eltwertowski (1976).

tranquillity. Part of this middle epoch corresponds to the Bretton-Woods 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 floating for most of the modern epoch, does the evidence in Figure 2.1 provide a hint that floating rates go hand-in-hand with commodity-price volatility?

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

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. A higher β_i corresponds to higher non-diversifiable risk of holding commodity i, and if investors are 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) $$Dp_{it} = \alpha_i + \beta_i DP_t + \varepsilon_{it},$$

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 of 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, $\alpha_i = 0, \beta_i = 1$ and $E(\varepsilon_{it}) = 0,$ so the expected return coincides with that of the portfolio; that is, $E(r_i) = E(r_m)$.

Columns 2 and 3 of Table 2.3 present the estimates of equation (2.2) with metals ranked according to the estimated slope coefficient, β_i. Sulfur has the largest slope coefficient of 3.64, indicating its price increases by more than 3 percent when the overall price index increases by 1 percent, so it is highly sensitive to worldwide macroeconomic factors. This result, however, could possibly reflect the large crash and subsequent recovery in the sulfur price over 2009-10. Conversely, boron is the only metal that has an insignificant β_i with a value of 0.10, implying that its price is almost completely insensitive to systematic global factors. All 21 metals have insignificant intercept terms except for magnesium.

For a given metal, the fraction of the price variance explained by the global factor, as measured by DP_t, is the value of R^2 for the equation, while the remaining fraction, $1 - R^2$, is the proportion due to all other factors, which we take to be factors specific to the commodity in question. Columns 4 and 5 of the table contain the values of R^2 and $1 - R^2$ (Panel A of Figure 2.2 is a plot of the R^2). As $1 - R^2$ is greater than 50 percent in all cases, and averages 74 percent, the relative importance of commodity-specific risk is clear. 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 = 66 percent), copper, aluminium and sulfur (all with R^2 > 40 percent).

Plots of the individual prices against DP_t (not shown here) do not reveal any obvious departures from linearity, but as a further check we added a quadratic term to model (2.2), $Dp_{it} = \alpha_i' + \beta_i' DP_t + \gamma_i (DP_t)^2 + \varepsilon_{it}'$. As can be seen from column 8 of Table 2.3, the estimated γ_i coefficients are all very small and mostly insignificant. Furthermore, the R^2 values in panel B of Tale 2.3 are similar to those in panel A, so the global vs commodity-specific decompositions are substantially unaffected by the addition of the quadratic term.

When a major commodity-producing country has pricing power, changes in their currency value can influence world prices (that is, dollar prices). When the country also has a commodity currency – one that moves in sympathy with world commodity prices – the link between prices and the exchange rate is amplified, as discussed by Clements and Fry (2008). Thus, the greater volatility of real exchange rates under the current floating-rate regime (Mussa, 1986) could account for the higher volatility of commodity prices over this period, at least in part.[8]

To investigate the role of the exchange-rate regime, the sample period is divided into two sub-periods: (i) pre-1972 (1900–1971), corresponding to the fixed exchange rate regime; and (ii) post-1972 (1972–2013), corresponding to floating rates. Panel B of Figure 2.2 contrasts the two sets of R^2. Under floating rates, the average R^2 is more than twice that under fixed rates. This enhanced role of global factors during the second sub-period could be taken as supportive evidence for the hypothesis that more variability in currency values is associated with higher commodity-price volatility. Although the average R^2 is higher under floating rates, only about one-third of the variability of metal prices is accounted for by the global factor, leaving about two-thirds for commodity-specific factors.

Is there any relationship between the economic importance of a metal and its global-risk component? Figure 2.3 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. However, the relationship is loose and, surprisingly, gold and iron ore have much lower-than-expected global factors. 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.

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 ones. 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 data on 16 of the previous 21 metals to analyse the covariation between prices and volumes.[9] Define price and quantity indexes of the 16 metals in year t as

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[8] See also Deaton and Laroque (1992) and Cuddington and Liang (2003).

[9] We disregard three of the 21 metals whose volume data are missing for the early part of the period, boron, silicon and vanadium; and eliminate (i) iron and steel, to avoid any double counting with iron ore and (ii) tungsten because its value share is so small. The data used in this section are annual for the 64-year period 1950–2013 and come from the US Geological Survey (http://minerals.usgs.gov/ds/2005/140/). Prices are expressed in US dollars per metric tonne

$\log P_t = 1/16 \cdot \sum_{i=1}^{16} \log p_{it}$ and $\log Q_t = 1/16 \cdot \sum_{i=1}^{16} \log q_{it}$. The deviations of metal i from the average are

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

These are the relative price and relative volume of metal i, which are both dimensionless concepts and thus comparable across different metals. This x_{it}^p is the logarithmic difference between the price of metal i and the log of the geometric mean of the 16 prices; equivalently, $\exp\left(x_{it}^p\right)$ is the ratio of the price of i to the geometric mean price. The interpretation of x_{it}^q is similar. Consider a regression of prices on volumes

(3.2) $$x_{it}^p = \beta x_{it}^q + \varepsilon_{it}, \; i = 1, \ldots, 16, \; t = 1, \ldots, 64,$$

where ε_{it} is a zero-mean disturbance term with a constant variance. This equation has no intercept as prices and volumes are expressed as deviations from the means. The slope β is the elasticity of price with respect to volume, which is also known as the “price flexibility”.

Panel A of Figure 3.1 is a scatter plot of x_{it}^p against x_{it}^q for $i = 1, \ldots, 16, t = 1, \ldots, 64$. The vast majority of the points are scattered around a downward-sloping line with slope of approximately -0.9, which is an estimate of the price flexibility. As shown in panel B of the figure, 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 64 years, we can also estimate model (3.2) separately for each year, and Table 3.1 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 between -0.8 and -0.9.

If as an approximation we set the price flexibility to -1, model (3.2) takes a very simple form:

(3.3) $$\log p_{it} = \left(\log P_t + \log Q_t\right) - \log q_{it} + \varepsilon_{it},$$

The price of metal i now depends on two factors. The first is $\left(\log P_t + \log Q_t\right)$, which equals $1/16 \cdot \sum_{i=1}^{16} \log\left(p_{it} q_{it}\right)$, the average logarithmic value of metals produced in the year. This reflects the overall state of the metals market. The elasticity of each price with respect to the market is

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(which is equivalent to 1,000 kilograms), while volumes are in metric tonnes. The material in this section is related to Chen and Clements (2012).

unity, so prices move in proportion to the market. The second term is $-\log q_{it}$, which measures the impact of the volume produced 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 (made up of, say, 5 percent growth in prices and 5 percent volumes growth) and the volume produced of metal i also increases by 10 percent, so that $\log P_t + \log Q_t = \Delta \log q_i \approx 0.10$, then the price of i will be expected to 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 (3.3), the price of a metal is a simple combination of a market-wide factor, a metal-specific factor and a random term that represents all other factors.

Nutting (1977) used the following metal-pricing model

$$(3.4) \qquad \log p_{it} = \alpha_t + \beta' \log q_{it} + \varepsilon'_{it},$$

where ε'_{it} is a disturbance term. Using data for 14 metals, he obtained an estimated slope coefficient of approximately -0.7.[10] Nutting's work occupies a reasonably prominent place in the literature on metals pricing and the log-linear model (3.4) is known as "Nutting's Law". In view of definition (3.1), models (3.2) and (3.4) are the same, with $\alpha_t = \log P_t - \beta \cdot \log Q_t$, $\beta = \beta'$, $\varepsilon_{it} = \varepsilon'_{it}$. This accounts for the broad similarity between Nutting's estimate of β' of about -0.7 and our estimates of β falling in the range of -0.8 to -0.9.

Returning to Panel A of Figure 3.1, one notable pattern is the clustering of observations for each metal. This suggests that model (3.2) should be extended by adding a fixed effect for each metal:

$$(3.5) \qquad x^p_{it} = \alpha_i + \beta x^q_{it} + \varepsilon_{it}, i = 1,\ldots,16, t = 1,\ldots,64,$$

where α_i is the metal-specific intercept. As $\Sigma_{i=1}^{16} x^p_{it} = \Sigma_{i=1}^{16} x^q_{it} = 0$, the intercepts and disturbances of (3.5) satisfy $\sum_{i=1}^{16} \alpha_i = \sum_{i=1}^{16} \varepsilon_{it} = 0$. Table 3.2 contains the results for the whole period. It is evident that adding the fixed effects causes the estimated slope coefficient to become nearly zero (-0.11) but significant. 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 3.1) and the large cross-sectional dispersion,

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[10] 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).

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.

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 (3.2) and (3.4) 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.[11]

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 (3.2) or $\hat{\beta}'$ from (3.4), 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 ϕ, so that $p_{it} q_{it} = \phi M_t$. 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 if we ignore the disturbance term, is Nutting's equation (3.4) 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.

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[11] See Chen (2012) for a further analysis of this issue.

Fourth, there is a further issue of supply-side influences. 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.[12] 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 from both sides of the market.

Fifth, there have been some strident criticisms of Nutting's Law. Evans and Lewis (2005) consider model (3.4) to be too rigid, which is an entirely reasonable criticism as the basic model could readily 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 (3.4), 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 (3.2) as this involves *relative* prices on the left-hand side and *relative* volumes on the right. That is, as these variables are deviations from their respective indexes, which are the corresponding means, they are most likely stationary, not I(1). Some evidence on the time-series properties of the variables is contained in Table 3.3. Columns 2-5 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 stationary. Moreover, columns 6 and 7 of the table give the results of testing whether the residuals from equation (3.2), with the pooled OLS estimate of the slope β, have a unit root. Again, the nonstationary hypothesis can be rejected, which implies that a spurious regression is unlikely. But suppose for the purposes 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 -0.851 with asymptotic standard error 0.076, which is close to the above estimates. In any event, straightforward inspection

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[12] See, for example, Haynes (2012) and Winter (2012).

of the cross-sectional relationship of panel B of Figure 3.1 indicates that Nutting's Law is unlikely to be guilty of the spurious regression charge.[13]

Figure 3.1 reveals a striking relationship between mineral prices and volumes and seems to be too valuable to be easily discarded. Nutting's Law is attractive in its simplicity and should be regarded as a potentially useful pricing rule that is worthy of further attention as a way to enhance understanding of the workings of metal markets. This cautious wording is designed to convey the idea of the possibilities and promise of Nutting's Law, but not (at this stage) an unalloyed endorsement.

4. PRICES CYCLE

Why might prices exhibit cyclical patterns? Metal markets are continually hit with shocks of all kinds 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.[14]

We use data from the London Metals Exchange (https://www.lme.com) for six major non-ferrous metals, aluminium, copper, lead, nickel, tin and zinc. The prices are monthly from 1989/06 to 2015/03 and are expressed in US dollars of 2010 by deflating by the US Producer Price Index.[15]

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[13] 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 $1\big/-0.1=-10$, 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 not seem to be a decisive rejection of Nutting's Law.

[14] For prior studies on the cyclical behaviour of metal prices, see Cashin et al. (2002), Cole (2015), Davutyan and Roberts (1994), Ingram (2015), Labys et al. (1998) and Roberts (2009).

[15] 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.

Let p_{it} be the price of metal i in month t and q_{it} be the corresponding volume. As defined in Section 2, $M_t = \sum_{i=1}^{6} p_{it} q_{it}$ is the total value and $w_{it} = p_{it} q_{it} / M_t$ is the value share of i. The Divisia price index is $DP_t = \sum_{i=1}^{6} \overline{w}_{it} Dp_{it}$, where $\overline{w}_{it} = 1/2 \cdot \left(w_{it} + w_{i,t-1} \right)$ is the share averaged over months t and t-1, and here q_{it} is the volume of turnover on the LME.[16] There is a fair degree of comovement among metal prices, with correlations averaging about one-half. As expected, the price index is highly correlated with copper and aluminium (> 80 percent), the metals with the largest value shares.

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.[17] 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 4.1 and three features are worth noting. First, from columns 3 and 8, the average duration of slumps and booms is longest for nickel (29 months) and tin (20 months) respectively. Copper has both the shortest slump (14 months) and shortest boom (15 months). Second, slumps are on average 3 months longer than

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[16] 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). The LME weights correspond reasonably closely with those derived from price and production data published by the US Geological Survey used in Sections 2 and 3, albeit with a higher weight on copper. The mean weights for the overlapping 1990-2013 period are:

Source	Aluminium	Copper	Lead	Nickel	Tin	Zinc
LME	31.70	47.59	2.77	6.75	1.78	9.41
USGS	37.05	35.21	3.30	12.57	2.08	9.78

[17] 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.

booms. Third, the swings in prices are substantial: From columns 4 and 9, on average, prices change by roughly 60 percent during slumps and booms, while the average monthly amplitude in booms is marginally larger. 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.

Rarely does the price change at a constant rate and 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 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 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 at a faster rate; 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, $\left(C - 1/2 \cdot a \cdot d\right)/d$, which, when multiplied by 100, is (approximately) in terms of percent per month.

Columns 6 and 11 of Table 4.1 contain the excess 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. Note that this pattern is less prevalent in booms than in slumps, but the mean of the index for booms is still negative when the (atypical) Millennium Boom is excluded. This pattern of a negative index 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 that the excess indexes do not differ greatly for slumps and booms, so from this perspective there is no obvious asymmetry.

Another feature of Figure 4.2 is the "striped" pattern, which is quite similar across metals. This is suggestive of an underlying common cycle. 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 4.4 is a DNA plot of booms for all six metals. Looking at this figure vertically, the commonality of the timing of booms is apparent, again suggesting a common cycle.[18]

Table 4.2 gives the moments of the price cycles in both 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 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 -0.44 (last entry of column 8), so longer slumps are also moderately larger slumps (prices fall by more). For booms, these characteristics are less closely related (mean coefficient = 0.17). Third, growth tends to be lower for more lengthy booms, but the relationship is not particularly strong (from column 9, the average correlation is -0.39). The relation between duration and growth during slumps is strong with an average correlation of 0.60: The longer the slump, the lower is the per month price fall, on average. Fourth, conforming to expectation, amplitude and growth are positively correlated during booms, but less closely related over slumps, as shown in column 10.

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 4.3 sheds some light on these issues by giving the correlations across episodes for duration, amplitude and growth. Three features stand out from this table. First, from the second element of column 3 (-0.389), there is little evidence of dependence between the amplitude of prices in the previous boom and that of the current slump. However, from the fifth element of column 3, there is a stronger effect for the transition from a slump to a boom. Thus, on average, a larger fall in prices during slumps is

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

associated with a greater subsequent boom; the negative sign of the correlation here reflects the change in the sign of amplitude in going from a slump to a boom. Second, there is little or no duration dependence, so that longer booms (slumps) are not associated with longer subsequent slumps (booms). In fact, all features of the current phase (duration, amplitude and growth) are more or less independent of the length of the past phase. A third feature is that previous growth is also almost unrelated to all subsequent phase characteristics.

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, the expansion of iron ore production is 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 on the prices of individual metals wash out in the average price, the global factors are more or less orthogonal to market-specific ones. 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 expectations 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 useful fact" that should be subject to further research. Finally, although metal prices are cyclical (Fact Three), the precise nature of each cycle has many of its own characteristics layered on top of the “average” cycle. Obviously the cycle cannot be relied upon to exactly reproduce itself in the future. 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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Table 2.1 Value Shares, 21 Metals, 1964-2013

Metal	Value shares						Change 1964-2013
	1964	1974	1984	1994	2004	2013	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8) = (7) - (2)
1. Aluminium	9.91	12.53	10.62	13.24	12.84	8.22	-1.69
2. Boron	0.09	0.07	0.93	1.30	1.08	0.21	0.12
3. Chromium	0.51	0.72	1.07	0.94	1.60	1.74	1.23
4. Cobalt	0.18	0.23	0.39	0.33	0.61	0.25	0.07
5. Copper	10.14	12.06	5.75	10.22	10.06	11.38	1.24
6. Gold	5.02	6.42	8.49	12.31	7.41	10.57	5.55
7. Iron/Steel	38.83	34.37	37.41	36.23	36.16	26.22	-12.61
8. Iron ore	17.43	14.38	18.22	10.53	11.97	27.08	9.64
9. Lead	2.43	1.73	0.90	1.01	0.89	1.15	-1.28
10. Magnesium	0.39	0.21	0.54	0.44	0.48	0.35	-0.04
11. Manganese	1.83	1.48	1.74	1.73	2.50	2.27	0.45
12. Molybdenum	0.40	0.39	0.38	0.50	1.35	0.49	0.09
13. Nickel	2.06	2.95	1.85	2.60	4.32	2.14	0.08
14. Platinum	0.47	0.89	0.96	0.98	1.59	0.84	0.37
15. Silicon	1.42	1.53	1.26	1.56	1.74	1.68	0.27
16. Silver	1.03	1.40	1.72	1.05	1.00	1.64	0.62
17. Sulfur	1.49	1.45	2.48	0.71	0.50	0.40	-1.09
18. Tin	2.19	2.03	1.30	0.64	0.84	0.56	-1.63
19. Tungsten	0.25	0.39	0.26	0.14	0.18	0.31	0.06
20. Vanadium	0.10	0.17	0.22	0.16	0.28	0.16	0.05
21. Zinc	3.85	4.58	3.50	3.38	2.58	2.35	-1.50
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, Real Metal Prices, 21 Metals, 1900-2013
(Annual log-changes $\times 100$)

Metal	Mean	Median	Standard deviation			Minimum	Maximum	p-values for χ^2 test for normality
			1900-70	1971-2013	1900-2013			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1. Magnesium	-4.05	-2.97	15.58	16.49	16.39	-88.18	55.52	0.000
2. Aluminium	-2.00	-1.61	16.10	20.04	17.71	-61.95	58.43	0.023
3. Cobalt	-1.41	-0.99	55.79	32.73	48.34	-299.15	255.22	0.000
4. Boron	-1.32	-1.51	31.82	9.13	25.67	-177.69	101.05	0.000
5. Sulfur	-1.21	-1.96	17.95	105.80	66.78	-507.22	370.59	0.000
6. Vanadium	-0.97	-2.01	17.73	42.53	30.63	-103.66	96.59	0.003
7. Nickel	-0.63	-0.97	8.19	28.83	18.92	-56.81	100.45	0.000
8. Copper	-0.25	-0.75	17.23	19.55	18.15	-44.08	56.93	0.503
9. Zinc	-0.22	1.00	20.66	22.80	21.50	-59.21	100.81	0.000
10. Lead	-0.08	-0.23	16.24	19.21	17.44	-43.95	50.56	0.460
11. Tin	0.20	-0.06	19.23	20.43	19.69	-59.45	56.75	0.255
12. Iron/Steel	0.24	-0.30	4.75	8.70	7.34	-31.91	25.79	0.001
13. Silver	0.28	-1.35	13.03	26.80	19.50	-75.91	59.50	0.010
14. Chromium	0.37	0.00	20.58	24.09	22.06	-62.98	56.66	0.086
15. Iron ore	0.39	0.73	10.08	11.27	10.56	-35.91	31.28	0.063
16. Molybdenum	0.74	-0.69	36.04	41.20	38.33	-114.10	122.06	0.009
17. Manganese	0.82	-0.21	23.63	21.85	23.05	-101.10	69.21	0.000
18. Silicon	0.85	-0.16	17.69	18.07	17.87	-65.21	45.41	0.032
19. Gold	0.88	-1.32	7.33	19.94	13.87	-37.15	57.12	0.000
20. Tungsten	0.98	1.18	30.74	26.68	29.26	-87.88	136.67	0.000
21. Platinum	1.23	1.19	21.04	25.69	22.92	-74.53	112.90	0.000
All metals	-0.28	-0.29	8.29	16.32	12.02	-59.88	36.54	

Notes:

1. The prices of five metals are not available for the whole period: iron and steel prices are available for the sub-period1940-2013; magnesium for 1915-2013; molybdenum for 1912-2013; silicon for 1923-2013; and vanadium for 1910-2013.
2. The normality test uses the D'Agostino et al. (1990) statistic with Royston's (1991) adjustment.

Table 2.3 Decomposition of Metals Price Volatility, 21 Metals, 1900-2013

	A. Linear Model, $Dp_{it} = \alpha_i + \beta_i DP_t + \varepsilon_{it}$				B. Quadratic Model, $Dp_{it} = \alpha_i' + \beta_i' DP_t + \gamma_i \left(DP_t\right)^2 + \varepsilon_{it}'$				
Metal	Intercept α_i	Slope β_i	Factor Component (%)		Intercept α_i	Linear term β_i	Quadratic term $\gamma_i \times 100$	Factor Component (%)	
			Global	Commodity				Global	Commodity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1. Boron	-1.29 (2.43)	0.10 (0.20)	0.24	99.76	-1.28 (2.61)	0.10 (0.21)	-0.01 (0.64)	0.24	99.76
2. Iron ore	0.46 (0.96)	0.25 (0.08)	8.03	91.97	-0.83 (0.97)	0.33 (0.08)	0.91 (0.24)	18.85	81.15
3. Gold	0.99 (1.24)	0.40 (0.10)	11.76	88.24	-0.20 (1.28)	0.47 (0.10)	0.84 (0.32)	17.10	82.90
4. Iron/Steel	0.20 (0.51)	0.46 (0.04)	65.96	34.04	0.29 (0.54)	0.46 (0.04)	-0.06 (0.11)	66.07	33.93
5. Magnesium	-3.79 (1.47)	0.66 (0.12)	22.68	77.32	-4.38 (1.55)	0.70 (0.13)	0.43 (0.37)	23.76	76.24
6. Silicon	0.75 (1.70)	0.69 (0.14)	20.45	79.55	0.31 (1.80)	0.71 (0.15)	0.32 (0.41)	20.98	79.02
7. Silver	0.48 (1.67)	0.69 (0.14)	18.29	81.71	-0.90 (1.75)	0.78 (0.14)	0.97 (0.43)	21.92	78.08
8. Nickel	-0.43 (1.59)	0.73 (0.13)	21.29	78.71	-0.62 (1.71)	0.74 (0.14)	0.14 (0.42)	21.37	78.63
9. Lead	0.13 (1.42)	0.75 (0.12)	26.68	73.32	-0.02 (1.52)	0.76 (0.12)	0.10 (0.37)	26.73	73.27
10. Platinum	1.45 (1.98)	0.79 (0.16)	17.04	82.96	2.40 (2.11)	0.73 (0.17)	-0.66 (0.52)	18.26	81.74
11. Zinc	0.01 (1.83)	0.80 (0.15)	20.03	79.97	-1.06 (1.93)	0.87 (0.16)	0.75 (0.47)	21.82	78.18
12. Manganese	1.05 (1.96)	0.85 (0.16)	19.71	80.29	1.13 (2.10)	0.85 (0.17)	-0.05 (0.52)	19.72	80.28
13. Chromium	0.61 (1.84)	0.88 (0.15)	22.76	77.24	0.49 (1.97)	0.88 (0.16)	0.09 (0.48)	22.78	77.22
14. Aluminium	-1.74 (1.30)	0.94 (0.11)	40.59	59.41	-1.85 (1.39)	0.95 (0.11)	0.08 (0.34)	40.62	59.38
15. Copper	0.02 (1.33)	0.96 (0.11)	40.49	59.51	-0.57 (1.42)	1.00 (0.11)	0.42 (0.35)	41.26	58.74
16. Tin	0.47 (1.49)	0.98 (0.12)	36.08	63.92	-0.51 (1.58)	1.05 (0.13)	0.69 (0.39)	37.89	62.11
17. Tungsten	1.32 (2.39)	1.24 (0.20)	25.84	74.16	0.70 (2.56)	1.28 (0.21)	0.44 (0.63)	26.16	73.84
18. Vanadium	-0.71 (2.64)	1.30 (0.22)	25.01	74.99	-0.13 (2.81)	1.26 (0.23)	-0.42 (0.68)	25.29	74.71
19. Molybdenum	0.87 (3.30)	1.67 (0.28)	26.71	73.29	0.84 (3.52)	1.67 (0.29)	0.02 (0.84)	26.71	73.29
20. Cobalt	-0.83 (3.93)	2.07 (0.33)	26.53	73.47	0.28 (4.21)	2.00 (0.34)	-0.79 (1.03)	26.92	73.08
21. Sulfur	-0.20 (4.79)	3.64 (0.40)	42.96	57.04	5.85 (4.86)	3.27 (0.39)	-4.25 (1.19)	48.89	51.11
Mean			25.67	74.33				27.30	72.70

Note: Standard errors are in parentheses.

Table 3.1 Price Flexibility for Metals

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

Period (1)	Price flexibility β (2)	R^2 (3)
	A. Average by decade	
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
	B. Summary statistics over 1950–2013	
Mean	-0.85	0.90
Median	-0.87	0.90
Minimum	-0.77	0.94
Maximum	-0.94	0.81

Note: 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 64 estimates of the slopes and R^2 values. For estimates when the data are pooled over the 64 years, see Figure 3.1.

Table 3.2 Price Flexibility for Metals and Metal-Specific Intercepts, 1950–2013

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

Variable (1)	Coefficient (2)	
Volume, β	-0.11	(0.04)
Intercept α_i		
Aluminium	-0.95	(0.14)
Chromium	-2.00	(0.08)
Cobalt	0.95	(0.14)
Copper	-0.56	(0.12)
Gold	6.62	(0.26)
Iron ore	-4.37	(0.32)
Lead	-1.61	(0.08)
Magnesium	-0.79	(0.06)
Manganese	-2.31	(0.12)
Molybdenum	0.47	(0.10)
Nickel	0.22	(0.05)
Platinum	6.39	(0.36)
Silver	3.03	(0.18)
Sulfur	-4.18	(0.19)
Tin	0.49	(0.06)
Zinc	-1.40	(0.11)
R^2	0.99	

Note: Standard errors are in parentheses.

Table 3.3 Panel Unit Root Tests, 16 Metals, 1950-2013

Test statistic	Relative price		Relative volume		Residuals	
	Statistic	p-value	Statistic	p-value	Statistic	p-value
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Alternate: All panels are stationary						
Levin, Lin and Chu - t*	-2.973	0.0015	-4.454	0.0000	-3.527	0.0002
Alternate: Some panels are stationary						
Im, Pesaran and Shin - W	-3.420	0.0003	-3.449	0.0003	-3.603	0.0002
Alternate: At least one panel is stationary						
ADF - χ^2	51.194	0.0170	57.826	0.0034	56.579	0.0047
Phillips-Perron - χ^2	81.763	0.0000	72.656	0.0001	89.094	0.0000

Notes:

1. The null hypothesis is that all panels contain unit roots.
2. For all tests, the optimal lag length is selected on the basis of the AIC, and an individual constant is included. The optimal Bartlett kernel is also used for the Levin, Lin and Chu test.
3. Columns 6 and 7 refer to the residuals from equation (3.2) with the pooled OLS estimate of the slope.

Table 4.1 Summary of Phases in Metal Prices

Metal	Slumps					Booms				
	No. of episodes	Duration (months)	Log-change × 100			No. of episodes	Duration (months)	Log-change × 100		
			Amplitude	Monthly amplitude	Excess index			Amplitude	Monthly amplitude	Excess index
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Aluminium	8	19.3	-44.09	-2.42	-0.64	9	15.7	37.56	2.81	-1.49
Copper	8	14.3	-46.73	-3.72	-3.84	9	15.3	52.87	3.58	1.62
Lead	8	14.6	-56.08	-4.22	1.94	9	17.9	58.16	3.62	-0.37
Nickel	6	29.0	-97.38	-3.91	-2.59	7	16.9	92.12	5.87	0.04
Tin	5	26.4	-62.88	-4.13	-3.98	6	20.3	69.17	3.61	5.89
Zinc	6	25.2	-63.31	-2.86	1.30	7	17.5	59.18	3.59	6.34
Mean										
All	6.83	20.5	-59.85	-3.52	-1.17	7.83	17.1	59.82	3.79	1.39
No MB	5.33	27.9	-66.57	-3.69	-1.03	6.00	12.9	46.97	3.82	-0.97

Notes:

1. An episode is defined as a peak to trough for “slumps” and trough to peak for “booms”.
2. Columns 3-6 and 8-11 are averages.
3. Means are averaged across all episodes for all metals. The last row excludes the atypically long Millennium Boom (MB).

Table 4.2 Moments of Duration and Amplitude, Six Metals

Episode	Means			Standard deviations			Correlations		
	Duration	Amplitude		Duration	Amplitude		Duration-amplitude	Duration-growth	Amplitude-growth
		Total	Per month		Total	Per month			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
				A. Boom					
1989/06-1991/12	7.25	37.90	5.27	0.43	12.42	1.85	-0.23	-0.36	0.99
1991/12-1993/10	8.40	24.33	3.25	2.80	7.34	1.36	-0.57	-0.78	0.96
1993/10-1996/09	18.83	59.16	3.40	6.34	21.71	1.56	0.16	-0.49	0.77
1996/09-1999/01	9.67	34.30	3.52	1.25	12.36	1.01	0.57	0.21	0.92
1999/01-2001/10	12.40	39.28	2.92	3.93	27.83	1.33	0.76	0.59	0.97
2001/10-2009/01	32.00	127.13	4.61	17.71	50.15	1.99	0.83	-0.58	-0.05
2009/01-2013/06	21.67	92.24	4.70	6.18	16.15	1.67	0.15	-0.92	0.22
2013/06-2015/03	8.33	26.75	3.57	2.62	5.03	1.44	-0.27	-0.80	0.80
Mean	14.82	55.14	3.91	5.16	19.12	1.53	0.17	-0.39	0.70
				B. Slump					
1990/08-1992/07	14.00	-51.86	-3.77	4.08	12.37	0.38	-0.92	0.60	-0.23
1992/07-1995/01	18.67	-56.11	-3.13	8.28	24.35	0.99	-0.81	0.27	0.33
1995/01-1997/07	20.67	-38.76	-1.88	0.47	14.55	0.72	0.47	0.53	1.00
1997/05-2000/01	26.60	-62.02	-2.44	10.21	20.75	0.67	-0.84	0.43	0.12
2000/01-2006/10	28.83	-52.16	-2.36	21.76	20.09	1.15	-0.49	0.64	0.30
2006/10-2011/02	16.17	-120.17	-8.19	6.07	34.44	2.41	-0.36	0.83	0.21
2011/02-2014/08	28.20	-56.97	-2.32	10.63	14.13	0.90	-0.12	0.88	0.31
Mean	21.88	-62.58	-3.44	8.79	20.10	1.03	-0.44	0.60	0.29

Notes:

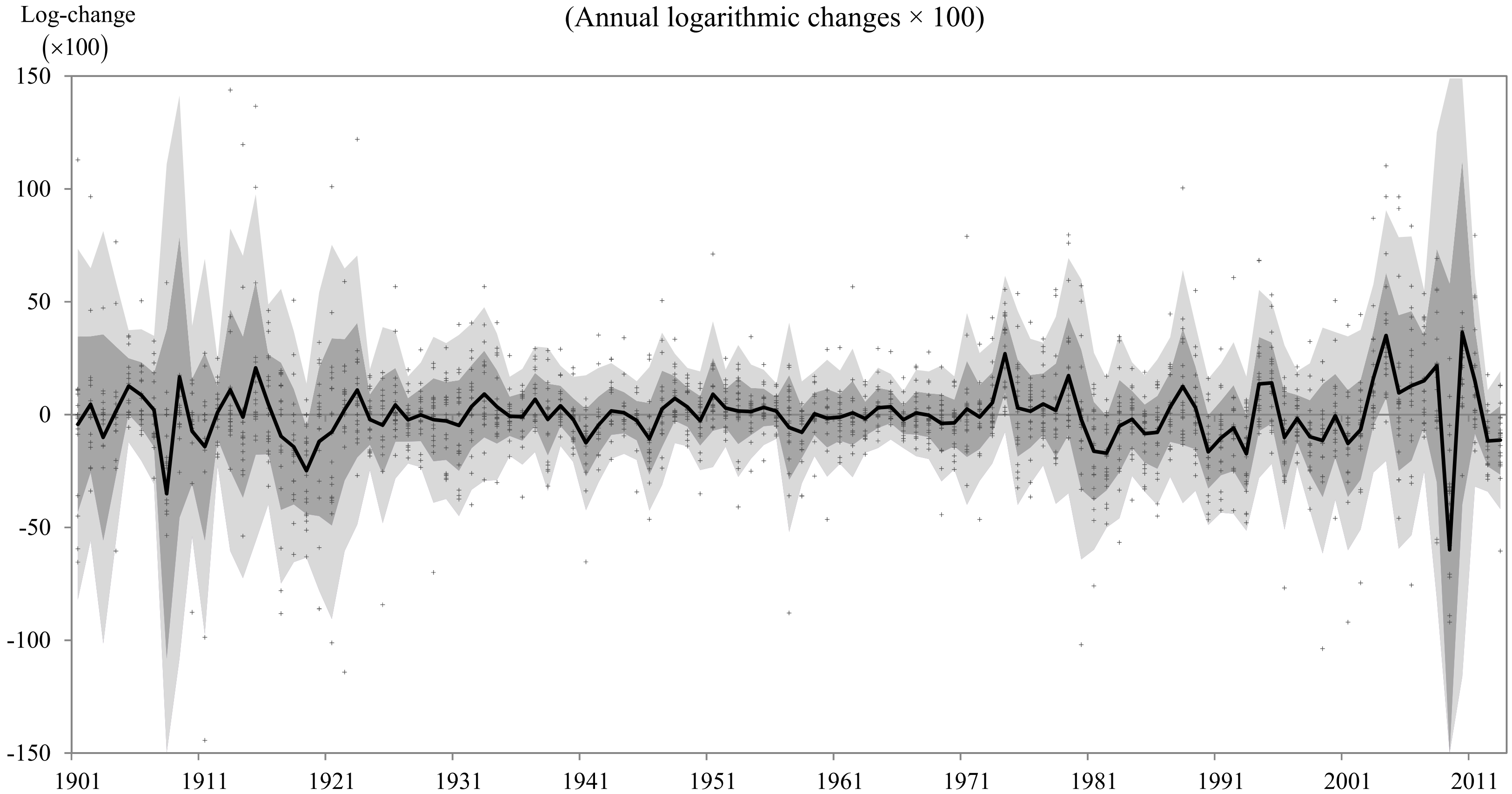
1. Units of columns 2 and 5 are months.
2. The elements of columns 3 are $100 \times \log(\text{peak price}/\text{trough price})$ for booms and the negative of this for slumps, that is, growth per episode.
3. The elements of columns 4 are $(100/\text{duration}) \times \log(\text{peak price}/\text{trough price})$ 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. The duration of a boom (slump) is then the period from the trough (peak) to the peak (trough). As the sample period is fixed, the two sets of segments obviously overlap.
5. 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 4.3 Correlations of Cycles, Across Episodes, Six Metals

Variable in previous episode (1)	Duration (2)	Amplitude (3)	Growth (4)
	Variable in current episode		
	A. Boom to slump		
Duration	0.301	-0.353	-0.088
Amplitude	0.234	-0.389	-0.257
Growth	0.046	-0.262	-0.230
	B. Slump to boom		
Duration	-0.051	0.077	-0.149
Amplitude	-0.305	-0.611	-0.348
Growth	-0.047	-0.119	-0.305

Note: To understand this table, take, for example, the first entry of column 2, 0.301. 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.

Figure 2.1 Relative Prices of 21 Metals, 1900-2013
(Annual logarithmic changes × 100)



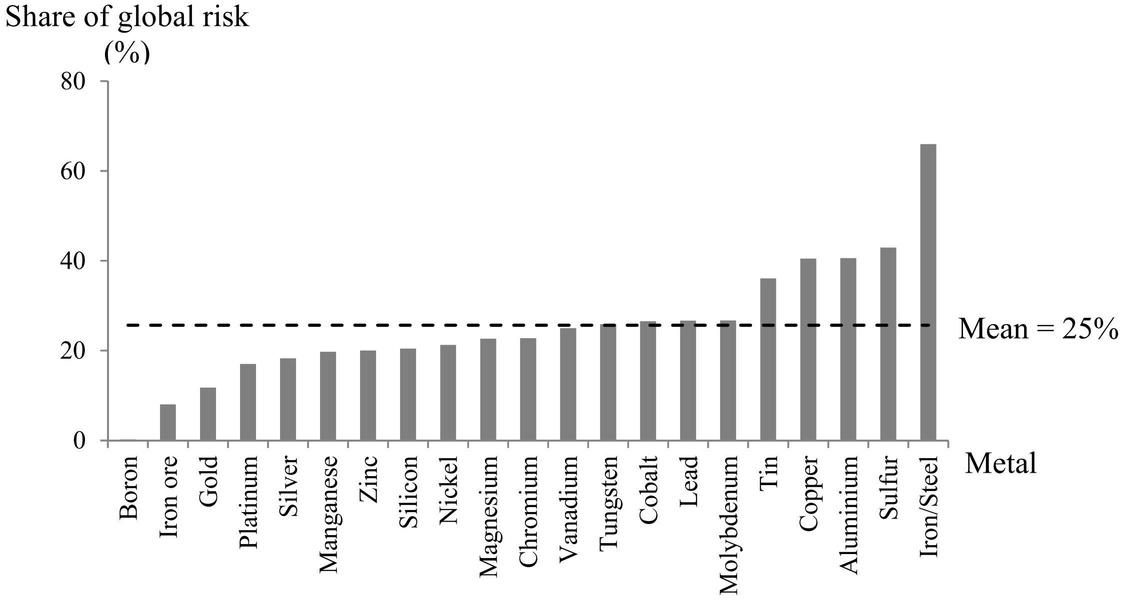
Notes:

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 +/- one (cross-sectional) standard deviation, and the light grey band is the mean +/- two standard deviations.
3. To enhance the visualisation, the log-changes are truncated at [-150,150]. Standard error bands that fall out of this range are also truncated accordingly.

4. SD is the average over time of the cross-sectional standard deviations.

Figure 2.2 Share of Global Risk Component, 21 Metals

A. Whole Period, 1900-2013



B. Two Sub-Periods for Exchange-Rate Regimes

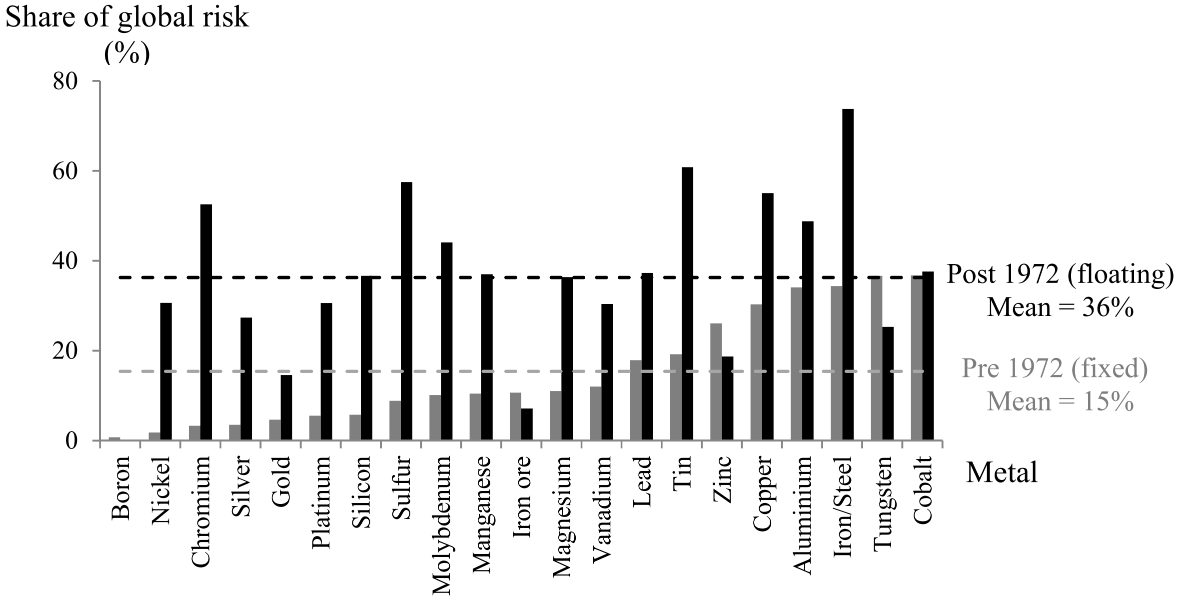
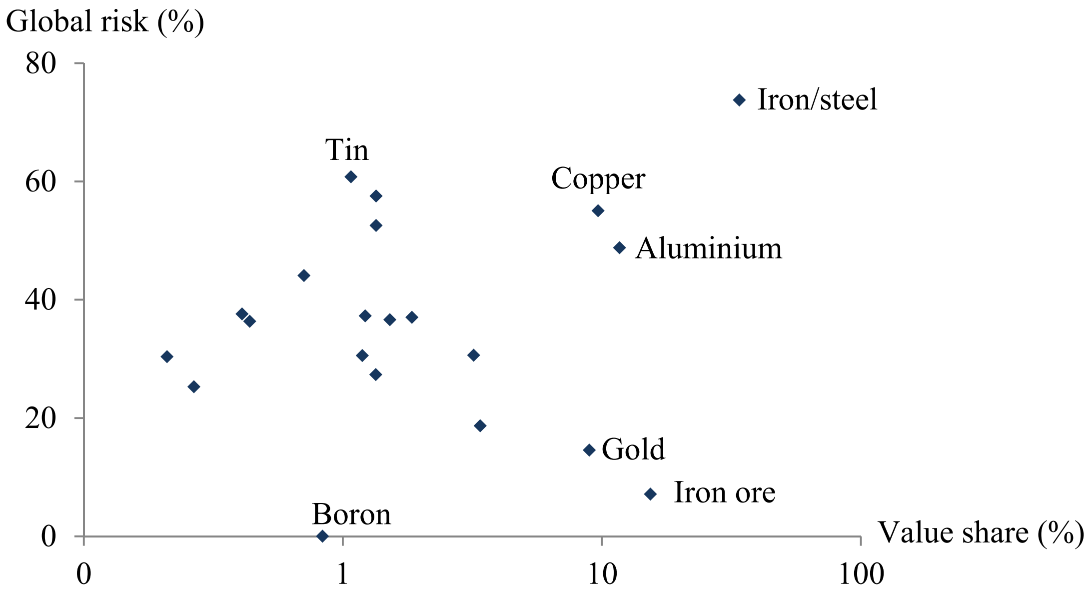


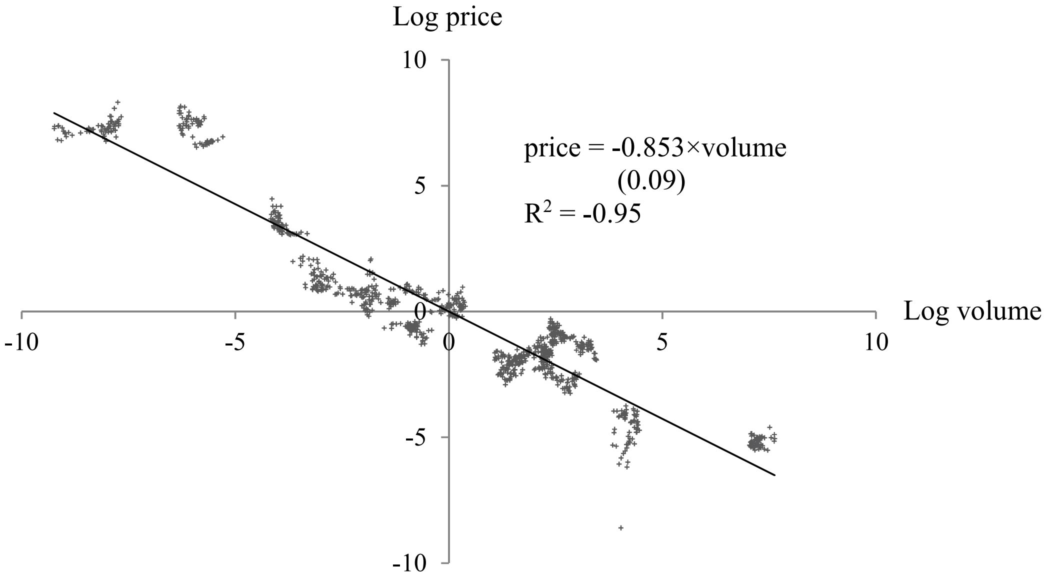
Figure 2.3 Economic Importance and the Global Risk Component, 21 Metals, 1972-2013



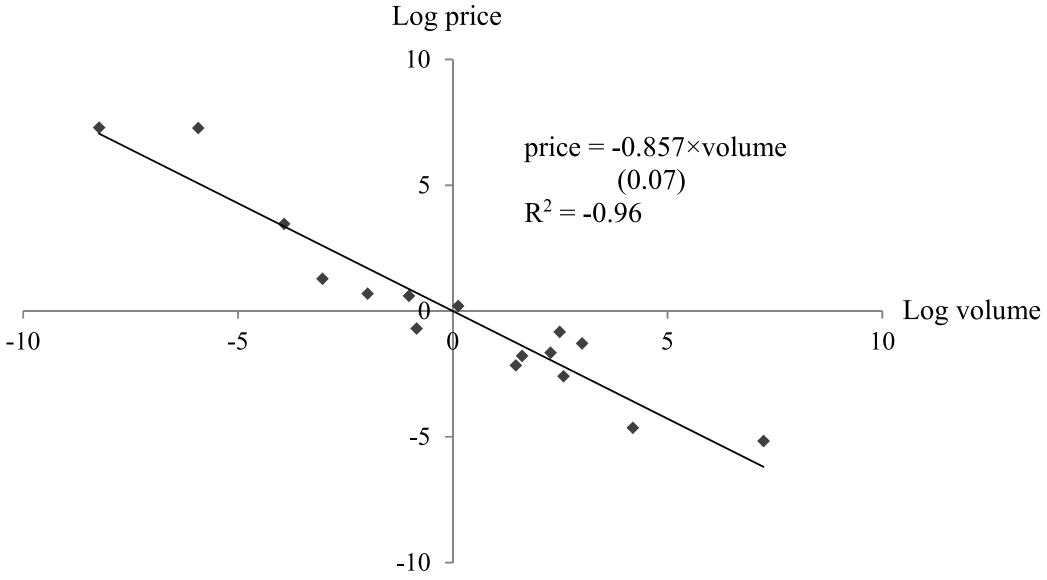
Note: The horizontal axis is on a log scale and refers to the value shares of the 21 metals, averaged over 1972-2013; the vertical axis refers to the R^2's for the same period.

Figure 3.1 Relative Prices and Volumes of 16 Metals, 1950–2013

A. Observations across Time and Metals
$(nT = 16 \times 64 = 1{,}024)$

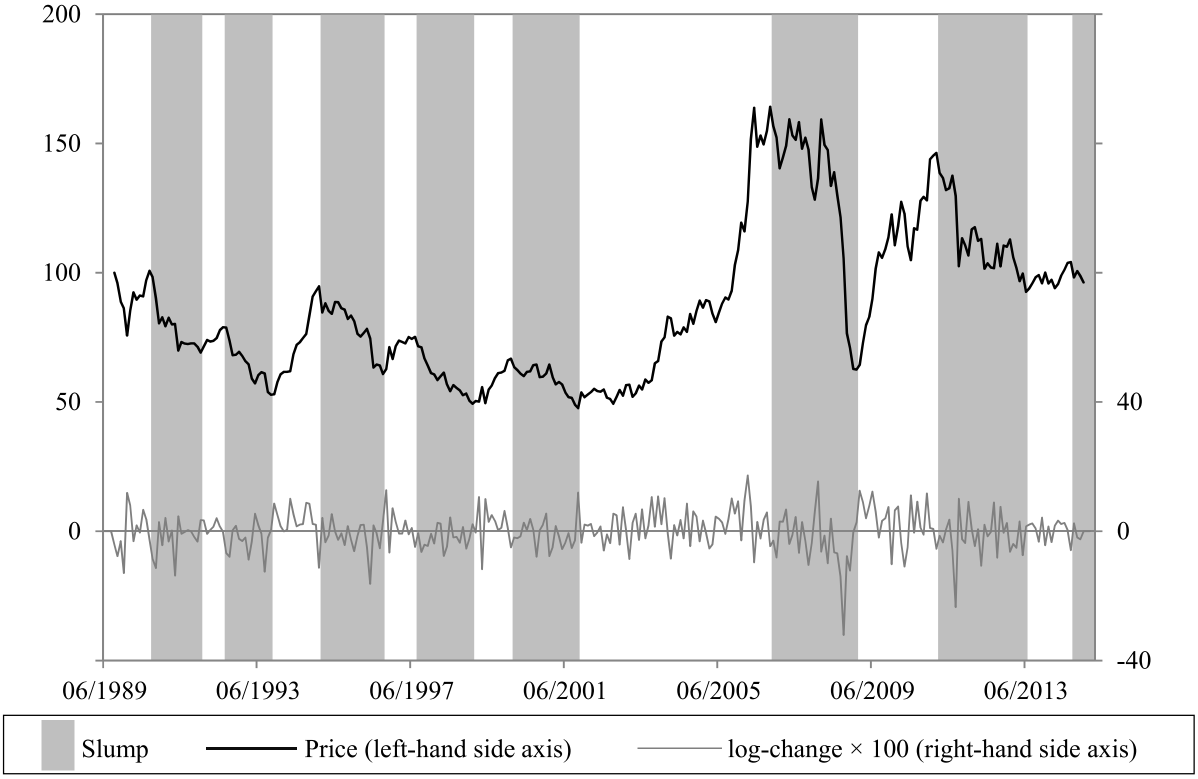


B. Observations across Metals
$(n = 16)$



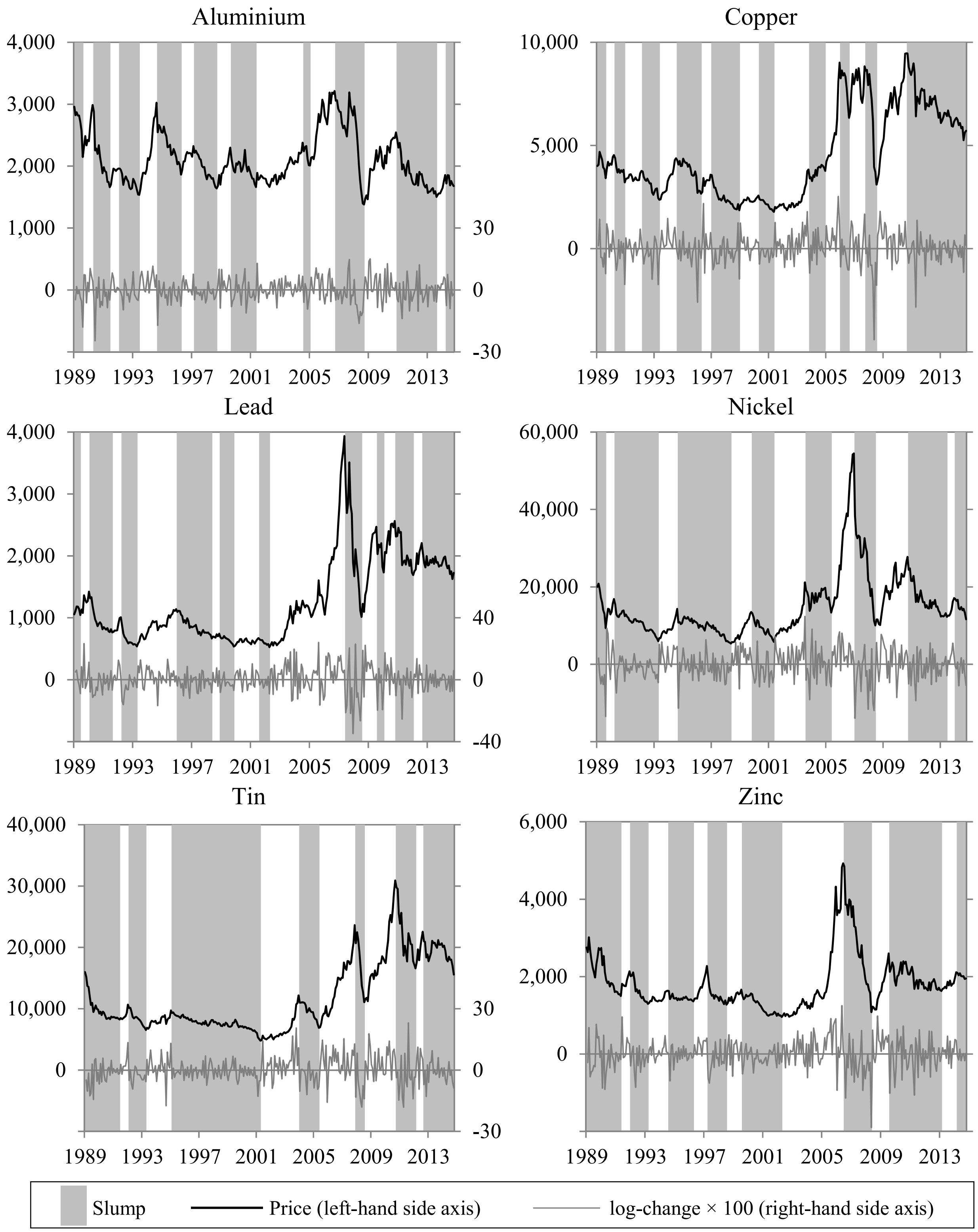
Note: Panel A is a scatter plot of prices against volumes for 16 metals in each of 64 years, with both variables measured as logarithmic differences from the means (*not* ×100 here). In Panel B, the 16 points represent averages over the 64 years of the relative price and volume of 16 metals. Standard errors are in parentheses.

Figure 4.1 Price Index



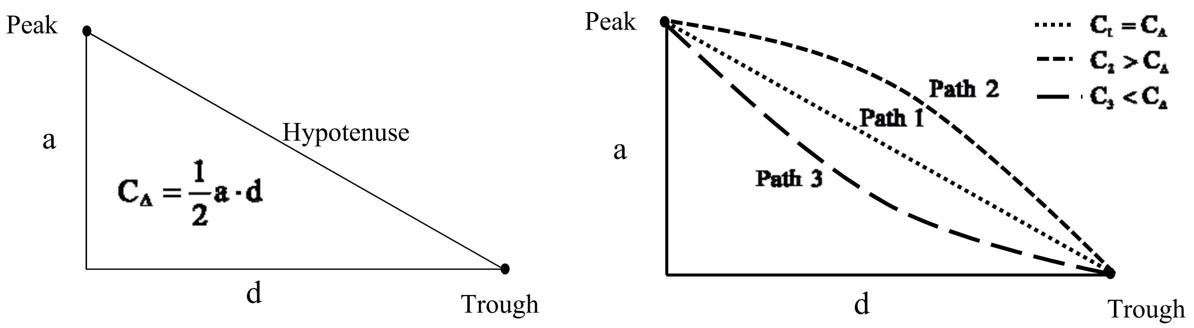
Note: The dark line is the level of the price index (in terms $US of 2010) with 1989M09 = 100. This index refers to the left-hand side axis. The grey line is the monthly log-change in the index, which refers to the right-hand axis. The shaded areas are the peak-to-trough slumps. The first shaded area 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 June 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).

Figure 4.3 A Triangular Measure of the Price Path



A. The Basic Triangle

B. Three Price Paths

C. Deviations from Hypotenuse

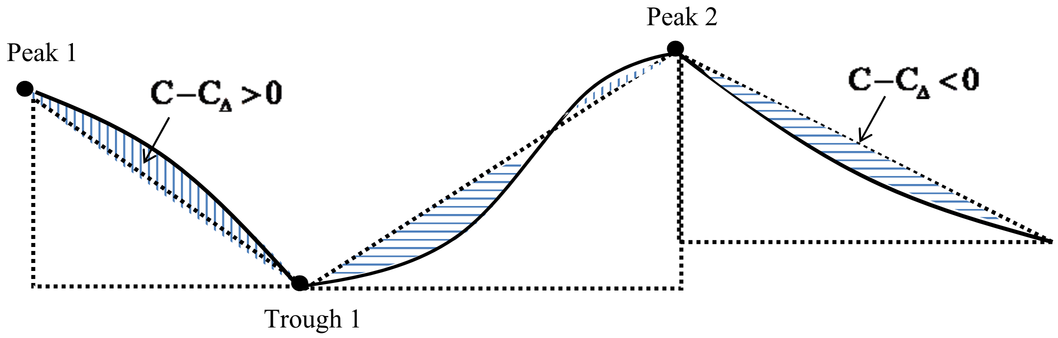
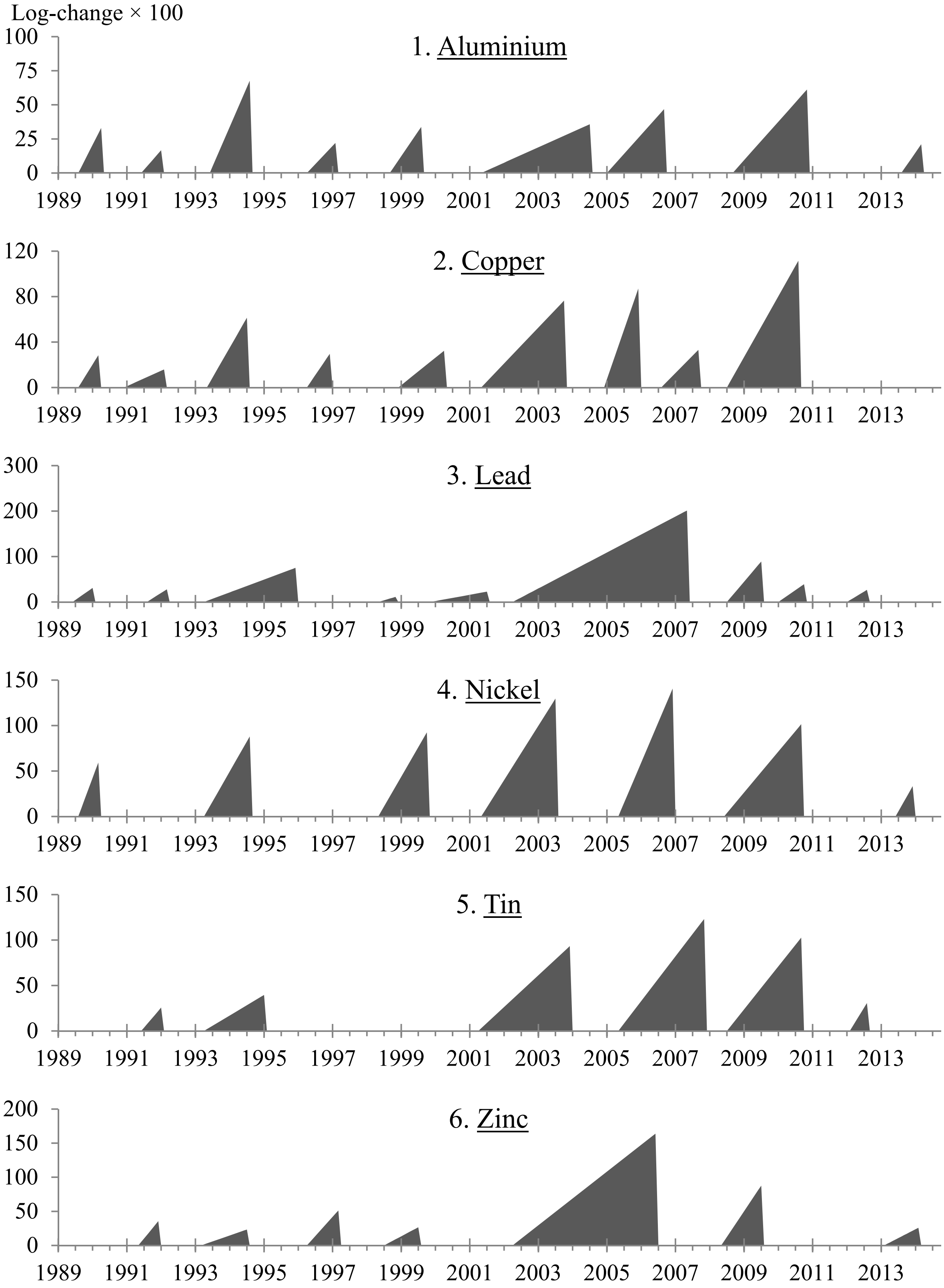


Figure 4.4 Duration and Amplitude of Booms



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