150 Years of Boom and Bust: What Drives Mineral Commodity Prices?

Martin Stuermer*

Job Market Paper

November 27th, 2013

Abstract

My paper is the first to provide long-run evidence on the dynamic effects of supply and demand shocks on mineral commodity prices. I assemble and analyze a new data set of prices and production levels of copper, lead, tin, zinc, and crude oil from 1840 to 2010. Price fluctuations are primarily driven by demand rather than supply shocks. Demand shocks affect the price persistently for up to 15 years, whereas the effect of supply shocks persists for a maximum of 5 years. My paper shows that price surges caused by rapid industrialization are a recurrent phenomenon throughout history. Mineral commodity prices return to their declining or stable trends in the long run.

JEL classification: E30, Q31, Q33, N50

Keywords: Mineral Commodity Markets, Prices, Non-renewable resources, Structural VAR

---

*Department of Economics, University of Bonn, Lennéstraße 37, 53113 Bonn, Germany. Email: martin.stuermer@uni-bonn.de. For helpful comments and suggestions, I thank Juergen von Hagen, Robert Pindyck, Lutz Kilian, Joerg Breitung, Martin Hellwig, Dirk Krueger, Christiane Baumeister, Gordon Rausser, Aaron Smith, Scott Irvin, Martin Helbling, Dirk Foremny, Benjamin Born, Felix Wellschmied, Peter Wolff, and participants in presentations given at UC Berkeley, UC Davis, U Illinois at Urbana-Champaign, Michigan SU, IMF, ECB, U Bonn, U Cologne, ZEW Mannheim, the Annual Meeting of the European Economic Association in Gothenburg, the ZEI summer school, the Annual Meeting of the Economic History Association in Boston, and the Annual Meeting of the Verein fuer Socialpolitik in Goettingen. All remaining errors are mine. I am grateful for research grants from the German Development Institute.

1 Introduction

The prices of mineral commodities, including fuels and metals, have repeatedly undergone periods of boom and bust over the last 150 years (Cuddington and Jerrett, 2008; Jacks et al., 2011). These long-term fluctuations affect the macroeconomic conditions of developing and industrialized countries (World Trade Organization, 2010; IMF, 2012). Strong booms have raised the issue of "security of supply" to the top of governmental agendas again and again.

However, the theoretical literature is far from conclusive on the driving forces behind these long-term fluctuations.[1] Extensions of the Hotelling (1931) model explain price fluctuations by referring to irregular exploration for deposits and hence, focusing on the supply side (Fourgeaud et al., 1982; Cairns and Lasserre, 1986). Competitive storage models ultimately leave the source of shocks open (Wright and Williams, 1982). Another strand of literature on the subject stresses the role of storage in the presence of expected supply shortfalls in explaining price fluctuations (Alquist and Kilian, 2010). Frankel and Hardouvelis (1985), Barsky and Kilian (2002), and other authors point to monetary policy as a major driving force. Finally, Dvir and Rogoff (2010) and other authors argue that price booms are due to persistent demand shocks combined with supply constraints.

Empirical work tends to focus on the oil market. Hamilton (2008) claims that supply shocks account for the broad behavior of the price of crude oil. In contrast, Kilian (2008b, 2009) and Kilian and Murphy (2012) show that fluctuations in the price of oil are driven mainly by demand shocks due to the global business cycle. Pindyck and Rotemberg (1990) stress that macroeconomic variables, such as money supply, help to explain the concurrent movements of commodity prices. Frankel and Rose (2010) find that, while global output and inflation have some effects on the prices of agricultural and mineral commodities, they are outstripped by volatility and inventories. Empirical evidence on storage models is also contradictory. Deaton and Laroque (1996) conclude that demand shocks are the dominant source of price fluctuations, while Cafiero et al. (2011) show that supply shocks are the main drivers.

This paper studies the dynamic effects of demand and supply shocks on mineral commodity prices from 1840 to 2010. It covers a considerably longer time period than most previous work, thus allowing me to include a long series of booms and busts in prices.

[1] See Carter et al. (2011) for a detailed summary of theories on fluctuations in commodity markets.

I chose mineral commodity markets which exhibit characteristics that make a long-run analysis feasible, notably those for copper, lead, tin, and zinc. These commodities were traded on the London Metal Exchange as fungible and homogeneous goods in an integrated world market over the long period considered here. They exhibit a substantial track record in industrial use. Hence, they have long-term characteristics that other mineral commodities such as iron ore, or coal have only gained in recent times. I also chose the crude oil market for comparison.

I assemble a new set of annual data which includes prices and world mineral production for copper, lead, tin, zinc, and crude oil, as well as world GDP. In contrast to Erten and Ocampo (2012), who examine "super-cycles" of different commodity price indexes over the period from 1865 to 2009, I am able to include data on the supply side and hence, am able to pin down the relative contribution of different shocks to the fluctuation of prices.

I employ a structural vector autoregressive (VAR) model to each of the five markets. I use long-run restrictions to identify three different shocks to the real price of the commodity concerned: "mineral supply shocks," e.g., a disruption in the physical production of the respective commodity due to strikes or cartel action; "world output-driven demand shocks," which include shocks in global demand for all commodities due to, e.g., an unexpected strong growth of world GDP; and "other demand shocks." The latter include all shocks that have no correlation with "mineral supply shocks" and "world output-driven demand shocks". I interpret them as mainly capturing unexpected changes in inventories.

My identification scheme allows me to leave the short-run relationships unrestricted. The restrictions on the long-run effects assume that shocks to the supply of a certain commodity and "other demand shocks" do not have long-run effects on world GDP. This implies the assumption that productivity losses due to searching for substitutes for copper, lead, tin, or zinc by other materials are too small to be of relevance to world GDP in the long term. "Other demand shocks" do not affect commodity production in the long run, which is based on the notion that changes in inventory demand only increase capacity utilization, but do not lead to capacity expansions of existing mines.

In a final step, I check the plausibility of the identified shocks through narrative evidence from the economic history of the examined markets.

The main conclusion drawn in this paper is that price fluctuations of the four mineral commodities studied here were primarily driven by demand shocks rather than by supply shocks. Demand shocks due to unexpected changes in world GDP have driven the large fluctuations in these commodity prices. The rise of China and its effect on prices is hence not a new phenomenon. Industrialization in the U.K., the U.S., and Japan had similar effects on mineral commodity prices. The strong impact of "world output-driven demand shocks" is in line with the results by Kilian (2009) and Kilian and Murphy (2012) on the oil market for the period after 1973. My results emphasize the importance of models that take into account demand shocks due to world GDP. Dvir and Rogoff (2010), Mitraille and Thille (2009), Bodenstein et al. (2012), and others have only recently begun to develop such theoretical models. My works points to demand shocks as an interpretation of shocks in competitive storage models (Gustafson, 1958a,b; Wright and Williams, 1982).

Shocks to the supply of a specific commodity are only of some importance in explaining fluctuations of tin and copper prices. Such shocks appear to increase with the importance of concentrated industry structures and government intervention in the markets. This evidence is in contrast to industrial organization models which predict that higher product market concentration will reduce price volatility (see Slade and Thille, 2006). My analysis suggests that extensions of the seminal Hotelling (1931) model, such as those by Arrow and Chang (1982), Fourgeaud et al. (1982), and Cairns and Lasserre (1986), which explain price fluctuations by supply shocks, must be rethought.

"Other demand shocks" also play an important role. My findings point to inventories as a source of fluctuations rather than a calming agent. This is in contrast to the classical competitive storage models. My results provide long-term evidence in support of Alquist and Kilian (2010), Kilian and Lee (2013), Kilian and Murphy (2013), and others who maintain that storage in the presence of expected supply shortfalls helps to explain price fluctuations. Narrative evidence in this paper, however, suggests that shocks due to changes in inventories are primarily driven by producer cartels and government stockpiling, and only in recent times by the "precautionary" behavior of consumers or investors in the markets examined here.

There are different dynamic effects of demand and supply shocks. "World output-driven demand shocks" and "other demand shocks" have large and statistically significant effects on the respective prices that persist for 5 to 15 years. "Supply shocks" exhibit a significant impact only on the prices of tin and copper for a maximum of 5 years. Whereas "world output-driven demand shocks" have a strong, significant, persistent, and positive effect on the production of lead and zinc, they have a positive, but only insignificant effect on the production of copper and tin.

The estimated linear deterministic trends are rather stable or even decreasing. This suggests that the current price boom is temporary rather than permanent in the long run.

The results for the markets of copper, lead, tin, and zinc are robust for different specifications, including different lag lengths, another identification scheme based on short run restrictions, and also in subperiods. The results do not change if I use a different data set including New York instead of London prices and employing different deflators.

Finally, the results for the market of crude oil confirm the empirical evidence provided by Kilian (2009), which indicates that demand shocks have been the main driving force for the period from 1973 to 2007. At the same time, my results show that during earlier periods, supply shocks have played an important role in driving the price of crude oil. The results for the market of crude oil are not robust for different sub-periods and lag lengths. This is possibly due to multiple structural changes in the time series for price and production (see Dvir and Rogoff, 2010; Alquist et al., 2011) and the rapid change in the importance of oil in the economy over time.

My results have important implications for commodity exporting countries. For optimal fiscal and macroeconomic policy responses in commodity exporting, developing countries, it is important to know, first, how persistent a unexpected price change is, and second, to identify the driving source behind the price change (see Barsky and Kilian, 2002; Kilian, 2008). My results suggest that commodity exporters should take a counter-cyclical policy stand rather than increasing long-term public investment based on the assumption of a permanent price increase. Since the current boom is mainly driven by "world output-driven demand shocks", which exhibit strong effects on the external and fiscal balances of commodity exporting countries, preparation for a down-swing of mineral commodity prices is all the more important. Finally, my results illustrate that self-imposed supply restrictions by a group of exporting countries are at most only temporarily effective in the copper and tin markets but are ineffective, as history shows, in increasing prices over the long-run.

For countries which import mineral commodities, my results indicate that if the past is any guide to the future, apprehensions about the security of the supply are rather exaggerated for the broadly used mineral commodities examined here. Various forms of subsidies for overseas mining and the reduction of import dependencies as well as "resource diplomacy", are questionable in effect given the fact that these mineral commodities are traded on world markets, and that prices react only moderately to supply restrictions in the short run.

I have organized the remainder of this paper as follows. In section 2, I describe the construction of my data set. Section 3 focuses on the econometric model and the scheme used to identify and distinguish the different structural shocks. In sections 4 and 5, I present empirical results and robustness checks for copper, lead, tin, and zinc. Section 6 gives empirical results and robustness checks for the case of crude oil. Section 7 offers conclusions.

2 A new data set for long-run analysis

I choose to examine those mineral commodity markets, notably copper, lead, tin, and zinc, where a long-run analysis is feasible. These markets have long-term characteristics that other mineral commodities, such as steel and aluminum, have only gained in recent times.

First, there is strong evidence that these four mineral commodities were traded in integrated world markets over the examined time period from 1840 to 2010 (see Klovland, 2005; O'Rourke and Williamson, 1994; Labys, 2008; Stürmer and von Hagen, 2012). This implies that price movements are in accordance with the law of one price across different areas of the world. The levels of prices might differ due to transportation costs or trade barriers, even though these two factors were relatively unimportant in these markets when compared to, e.g., steel or coal markets. During the two World Wars commodity markets disintegrated due to price and supply controls (Backman and Fishman, 1941; Findlay and O'Rourke, 2007). I will account for this by using yearly dummies for the war periods and the three consecutive years.

Second, London has been and still is the principal marketplace to establish prices in these markets (Schmitz, 1979; Rudolf Wolff & Co Lt., 1987; Slade, 1991). In comparison to U.S. price data, London prices reflect market prices over the entire time period rather than producer prices, as in some periods in the U.S. (see Table 3 in the Appendix).

Third, the four mineral commodities have been traded as rather homogeneous goods across time. For example, the purity of traded copper in 1900 was 99.97% while it is 99.99% today (see Table 3 in the Appendix). The other three mineral commodities possess this feature as well.

Fourth, these mineral commodities exhibit a substantial track record in industrial use and are still among the top twenty-five in value of world production. The four mineral commodities have been used for several thousand years. They are inputs either in pure form or as a alloys to a broad variety of intermediate and manufacturing goods. Their uses range from tools, home appliances, electronics and machinery to transportation and construction.

To ease comparison to the literature, I have also collected data for the crude oil market. In contrast to the other four mineral commodities, the market has undergone major structural changes (Kilian and Vigfusson, 2011; Dvir and Rogoff, 2010) in the use of crude oil. Crude oil was mainly used for the production of kerosene for lighting during the 19th and beginning 20th century, and then rapidly as a source of energy for automobiles (Yergin, 2009). There is to my knowledge also no empirical evidence regarding historical integration of the oil market even though narrative evidence from Yergin (2009) suggests that American kerosene rapidly became an internationally traded good after the first discovery of oil in Titusville in 1859.

I have compiled annual data for real prices and world production of copper, lead, tin, and zinc, as well as world GDP over the time period from 1840 to 2010. For crude oil, data is available only from 1861 onwards. All sources are shown in Tables 2 to 6 in the Appendix.

With respect to world market prices, I make use of annual nominal price data for copper, lead, tin, and zinc from the London Metal Exchange (LME) and its predecessors. The prices are in British pounds (£) for most of the period covered in this study. Starting in the middle of the 1970s, they have been given in U.S. dollars ($), and I have transformed them to British pounds by using annual exchange rates. For robustness checks, I have collected U.S.-American prices. I obtained nominal world market prices for crude oil from British Petroleum (2011).

Following Krautkraemer (1998) and Svedberg and Tilton (2006), I deflate all nominal prices by the respective consumer price indices (CPI) for the U.K. and the U.S. I use producer price indices (PPI) as a robustness check. To obtain the U.S.-PPI, I have spliced together the wholesale price index for all commodities by Hanes (1998) and the producer price index for all commodities from the U.S. Bureau of Labor Statistics (2011). I have constructed the U.K.-PPI based on data from Mitchell (1988) and the World Bank (2012) in the same way.

Insert Figure 1 about here.

I have assembled data on the world production of the five mineral commodities from several sources. I use mine output or smelter output for earlier times and refined output where available for the 20th century. World production includes production from primary as well as recycled materials. However, the differentiation between primary and secondary materials is not easy, since so-called "new scrap" accrues across the different stages of the production process. "New" and "old" scrap are also fed back in the production process at different stages according to quality. Overall, I have tried to keep the data series as consistent as possible.

I use world GDP data from Maddison (2010) and The Conference Board (2012) as a measure of global economic activity that drives the demand for mineral commodities.[2] Maddison's data set only provides annual world GDP data from 1950 onwards. I sum up country based annual data for the time period before 1950. For those years where country-based annual data is missing, I interpolate the data with linear trends. For European countries and Western offshoots, I compute their respective shares of output relative to neighboring countries, where data is available. I then interpolate these shares and multiply them with data from those countries, where annual data is available. This process assumes that the business cycle of these countries moves in tandem to that of their neighboring countries.

3 Identifying shocks to mineral commodity prices

I use a three-variable, structural VAR model with long-run restrictions to decompose unpredictable changes in real mineral commodity prices into three mutually uncorrelated shocks, notably "world output-driven demand shocks", shocks to the supply of the respective commodity, and "other demand shocks".[3]

The basic idea of the variance decomposition is to find what amount of information each variable, notably world GDP and world mineral production, contributes to the world mineral commodities price in the autoregression. It hence shows how much of the predicted error variance of the mineral commodity price can be explained by exogenous shocks to world GDP and world mineral production.

The vector of endogenous variables is $z_t = (\Delta Y_t, \Delta Q_t, P_t)^T$, where ΔY_t refers to the percentage change in world GDP, ΔQ_t denotes the percentage change in world primary production of the respective mineral commodity, and P_t is the log of the respective real commodity

[2]This is in contrast to Kilian (2009) and Kilian and Murphy (2012) who create and employ a freight rate index. They argue that this is a better proxy for business cycle driven demand for oil as it does not include, e.g., effects of fluctuations of economic activity in the service sector. However, I decided to use world GDP because to my knowledge it is the only proxy for which data is available over the period considered.

[3]Blanchard and Quah (1989) have introduced this methodology to explain fluctuations in GNP and unemployment, while I use this methodology to explain fluctuations in mineral commodity prices. It is therefore important to keep in mind that Blanchard and Quah (1989) identify and interpret demand and supply shocks at the aggregate level, whereas I do so at the level of a specific commodity market.

price. The matrix of deterministic terms D_t consists of a constant, a linear trend, and annual dummies during the two World War periods and the three years immediately after. The structural VAR representation is

$$Az_t = \Gamma_1^* z_{t-1} + ... + \Gamma_p^* z_{t-p} + \Pi^* D_t + B\epsilon_t \ . \tag{1}$$

The reduced form coefficients are $\Gamma_j = A^{-1}\Gamma_j^*$ for $(j = 1, ..., p)$, and ϵ_t is a vector of serially and mutually uncorrelated structural innovations. The relation to the reduced form residuals is given by $u_t = A^{-1}B\epsilon_t$. I choose the number of lags p according to the Akaike information criterion (AIC) for the benchmark regressions.

To compute the structurally identified impulse responses, I estimate the contemporaneous impact matrix $C = A^{-1}B$ by $\hat{C} = \hat{\Phi}^{-1}\hat{\Psi} = \hat{\Phi}^{-1}\text{chol}[\hat{\Phi}\hat{\Sigma}_u\hat{\Phi}']$. The matrix of accumulated effects of the impulses is $\Phi = \sum_{s=0}^{\infty}\Phi_s = (I_K - \Gamma_1 - ... - \Gamma_p)^{-1}$. I need $K(K-1)/2 = 3$ restrictions on the long-run matrix of structural shocks Ψ to identify the structural shocks of the VAR. I hence assume that Ψ is lower triangular and obtain it from a Choleski decomposition of the matrix $\hat{\Phi}\hat{\Sigma}_u\hat{\Phi}'$. (See Lütkepohl and Krätzig, 2004)

Assuming that Ψ is lower triangular means that I place zero restrictions on the upper-right hand corner of the long-run impact matrix. Thereby, I make the assumption that shocks to the supply of the respective mineral commodity and "other demand shocks" affect world GDP in the short-run, but not in the long-run. Furthermore, "other demand shocks" exhibit only a transitory effect on mineral commodity production. These assumptions lead to the identification of the following three shocks:

World output-driven demand shocks

I construct the "world output-driven demand shocks" in such a way as to capture shocks to the global demand for all mineral commodities due to unexpectedly strong expansions or contractions of world GDP. They thus include unexpectedly strong periods of industrialization such as those of Great Britain, Germany, and the U.S. in the 19th century, Japan in the 20th century, and China and other emerging economies at the beginning of the 21st century.

The long-run restrictions mean that I refer to "world output-driven demand shocks" as those shocks to global real GDP that are neither explained by the short-run effects of shocks to the supply of the respective mineral commodity nor by the short-run effects of "other demand shocks".

I hence impose the restriction that shocks to the production of the mineral commodity which are not driven by "world output-driven demand shocks" only have a temporary effect on world GDP. This assumption seems strong, as one might argue that a reduction in inputs of a certain commodity might affect productivity and hence, world GDP in the long term. However, Barsky and Kilian (2004) state that U.S. productivity losses due to the search for substitutes for oil are too small to be relevant. They sum up that none of the models which establish a link from oil price shocks to productivity changes "can claim solid empirical support." Kilian (2009) demonstrates that unanticipated oil supply shocks exhibit a statistically significant impact on the level of U.S. GDP only for the first two years and then become insignificant. Since the other mineral commodities examined here are of even less importance to world GDP than crude oil, I believe that my assumption is reasonable.

Moreover I assume that shocks to mineral commodity prices due to "other demand shocks" exhibit no long-term effect on world GDP. Certainly an increase in a commodity price decreases the income of consumers in the importing countries. At the same time, it increases the income of consumers in exporting countries so that there is no effect on world GDP from the aggregate demand side. Even in the case of crude oil, Rasmussen and Roitman (2011) show that oil price shocks on a global scale exhibit only small and transitory negative effects on a slight majority of countries.

Supply shocks

"Supply shocks" capture shocks to the production of the respective mineral commodity due to unexpected changes in production caused by, e.g., cartels, strikes, or natural catastrophes. I define them as those innovations to the production of the respective commodity that are driven neither by the short and long-term effects of "world output-driven demand shocks", nor by the short-term effects of "other demand shocks". I hence assume that "supply shocks" and "world output-driven demand shocks" affect the world's production of the respective commodity in the long run. In contrast, price changes driven by "other demand shocks" exhibit only a transitory effect on the world production of the respective mineral commodity. They hence affect only capacity utilization of the extractive sector, but not long-term investment decisions. This is plausible, given the fact that expanding extraction capacities exhibits high upfront costs and takes many years (Radetzki, 2008; Wellmer, 1992).

Other demand shocks

"Other demand shocks" encompass all innovations to the respective real mineral commodity price that are driven neither by "world output-driven demand shocks" nor "supply shocks". "Other demand shocks" hence capture all shocks that are uncorrelated to these two latter shocks. I interprete these shocks as mainly capturing changes in the demand for inventories of mineral commodities which stem from three different sources: 1) government stocking programs, 2) producers with market power who increase their inventories in an attempt to increase prices, and 3) shifts in expectations of the downstream processing industry about the future supply and demand balance (see Kilian, 2009; Kilian and Murphy, 2012, on the last point). I do not directly include a proxy for inventories in this study because long-term data is missing.

"Other demand shocks" may also include unexpected changes in the intensity of use of the respective mineral commodity in the production of world GDP. The intensity of use reflects the quantity of a mineral commodity that an economy needs to produce one unit of output. It is driven by several factors: 1) technical improvements that either decrease or increase the quantity of a mineral commodity used to produce a specific good, 2) substitution by other materials, 3) changes in the structure of world output (e.g., a higher share of services), fourth, saturation of markets, and 4) government regulations that change the use of materials (for example, the phase-out of lead additives in gasoline see (Cleveland and Szostak, 2008)). However, all of these factors have partly offsetting effects and are rather gradual, long-term processes, especially on the global level (see e.g., Pindyck, 1980). Even government regulation, such as that imposed on lead additives, has become set in a continuous process of phasing-out over several decades. These gradual processes are primarily captured in the long-run deterministic trend in the regression.

4 Empirical results

I employ ordinary least squares to consistently estimate the reduced-form coefficients of the VAR models of each of the five mineral commodity markets. On the basis of these estimates, I obtain the contemporaneous and long-run matrices by the Cholesky decomposition described above. I use a recursive-design wild bootstrap with 2000 replications for inference, following

Goncalves and Kilian (2004). See Tables 7 to 17 in the Appendix for the estimated coefficients.

In the following, I set out the main results for each of the mineral commodities examined. I present the respective impulse response functions which plot the respective responses of world GDP, world mineral commodity production, and real copper prices to a one-standard deviation of the three respective structural shocks. I use accumulated impulse response functions for the shocks to world mineral commodity production and world GDP to trace the long-term effects on the levels of these variables.

I compare the identified structural shocks to evidence from economic history. This helps to better understand the dynamics of the markets and to give the identified shocks a proper interpretation. I do so with the help of two figures: First, I present the evolution of the three structural shocks to the respective mineral commodity price. Second, I show the historical decomposition of each mineral commodity price which quantifies the contribution of the three structural shocks to the deviation of the respective price from its base projection. Since the vertical scales across the three sub-panels are identical, they show the relative importance of a given shock.

4.1 Copper market

My results show that the fluctuations in the price of copper are mainly driven by "world output-driven demand shocks". "Supply shocks" and "other demand shocks" also play a pronounced role in determining medium-term swings in price. The narrative evidence suggests that the copper market is characterized by a long history of oligopolistic structures. Chandler (1990) points out that the five largest U.S. copper producers in 1917 were still under the top five in 1930 and in 1948. In addition, copper production has also always been strongly concentrated, with the main producers in Chile and the U.S. (Schmitz, 1979).

Insert Figure 2 about here.

The impulse response functions in Figure 2 show that a positive "world output-driven demand shock" exhibits a strong, positive, and persistent effect on world GDP. It causes a positive and significant increase in copper production that lasts for about three years. Finally, it triggers a major increase in the real price of copper for a maximum about one year after the shock. The shock continues to persist significantly over a period of more than ten years.

A positive shock to the supply of copper has a positive and significant effect on GDP for three to ten years and then approaches zero, in accordance with our identifying assumptions. The supply shock has a strong and persistent effect on copper production. Moreover, it reduces the real price of copper significantly for more than ten years, with an insignificant period of three to five years after the shock.

A positive "other demand shock" has by assumption only a transient effect on world GDP and copper production. Its impact on the real price of copper is immediate and statistically significant for the first two years and then again five to ten years after the shock.

The historical account of events in the copper market for the period from 1840 to 2010 is basically in line with the identified structural shocks in Figure 3 and the accumulated effects of the structural shocks in Figure 4. In the late 1840s the price of copper was low owing to the British railway crisis from 1847 to 1848 (see Kindleberger and Aliber, 2011), which caused negative "world output-driven demand shocks". In the 1850s the price underwent a major upswing, driven mainly by positive "world output-driven demand shocks" due to the world economic boom at that time (see Kindleberger and Aliber, 2011). In the mid 1850s, prices stopped rising even though "world output-driven demand shocks" still persisted. Large positive supply shocks due to the "copper mania" (Richter, 1927, p. 246), the opening of copper mines in the Southern Appalachians of the U.S., put downward pressure on the price of copper, which experienced a long downturn during the 1860s, reaching a trough around 1870. This was due to negative "world output-driven demand shocks" triggered by the Panic of 1857, the U.S.-American Civil War from 1861 to 1865, and the Overend-Gurney Crisis in 1866 and their respective economic aftermaths (see Kindleberger and Aliber, 2011). At the same time, there was some downward pressure caused by positive "supply shocks" due to the opening of new mines in Arizona and Michigan - despite the problems posed by the Civil War - and a substantial increase in production in Chile and elsewhere in the world, especially in the late 1860s (Richter, 1927).

Insert Figure 3 about here.

After the price peaked at the end of the 1870s owing to positive "world output driven demand shocks", it fell until the mid 1880s. This was caused by two shocks. First, the Long Depression beginning in 1873 led to strong negative "world output driven demand shocks"

(Kindleberger and Aliber, 2011). Second, major, positive "supply shocks" drove prices down. Between 1875 and 1885, annual U.S. copper production rose by more than 500 percent. The Anaconda mine in Montana "proved fabulously rich and enormously productive" (Richter, 1927, p. 255), and several others mines opened in Arizona.

The mines in Michigan, which had already created a selling pool in the 1870s, reacted to the low prices with an aggressive rise in production and a sales policy aimed at driving out the new competitors (Richter, 1927, p. 256). This explains the major positive copper "supply shock" that drove prices down further in the first half of the 1880s. As many mines were unable to continue operating at a profit at these low prices, world production fell from 229,600 mt in 1885 to 220,500 mt in 1886 (Richter, 1927, p. 257). This explains the negative "supply shock" at that time.

In response, the Secrétan copper syndicate, which controlled up to eighty percent of world production, became active from 1887 to 1889 (Richter, 1927; Herfindahl, 1959), driving up the world market price to a high in 1887 by stockpiling copper (Richter, 1927; Herfindahl, 1959), as reflected in the strong "other demand shocks" at the time. However, the high prices led to increased production and oversupply, which the syndicate tried to compensate for by stockpiling even more (Richter, 1927; Herfindahl, 1959). This led to the syndicate's collapse in 1889. The Société Industrielle et Commerciale des Métaux, which handled the operations of the syndicate, and the main financing bank, Comptoir d'Escompte, were forced into bankruptcy, and the manager responsible committed suicide (Richter, 1927; Herfindahl, 1959). The copper from the inventories was sold over a period of three to four years, driving prices down until the mid 1890s (Richter, 1927, p. 259), as the accumulated effects of the "other demand shocks" show. "World output-driven demand shocks" also had a waning impact on prices over this period.

Prices increased again at the end of the 1890s, then experienced a downturn reaching a low around 1904, followed by another boom in the mid 1900s and then a further downturn. These cycles of boom and bust were driven by all three kinds of shock. After gradual economic recovery in the 1890s, positive "world output-driven demand shocks" peaked at the beginning of the 20th century, followed by recessions in 1904 and 1907, which were triggered by financial crises in the U.S. as described by Kindleberger and Aliber (2011) (see also data provided by Crafts et al., 1989; National Bureau of Economic Research, 2010). "Other demand shocks" and "supply shocks" also affected prices over that period. In the late 19th century, the

Amalgamated Copper Company, which controlled about one fifth of world copper production, and a number of other firms tried to stabilize the price of copper by withholding stocks from the markets and restricting output (Herfindahl, 1959, p. 81). This is also represented by spikes in the cumulative effects of both "other demand shocks" and "supply shocks". In late 1901 the company changed course by releasing copper from its stocks in order to undersell its competitors, which resulted in negative "other demand shocks" to the market. Subsequently, there were renewed attempts at price manipulation through the withholding of stocks from 1904 to 1905, 1906 to 1907 and, finally, 1912 to 1913 (Herfindahl, 1959, pp. 83-91). These manipulations play a major role in explaining the fluctuations in the price of copper at the time, as the accumulated effects of "other demand shocks" show. Finally, from 1910 onwards the introduction of fine grinding methods and milling by flotation made large-scale mine production from low-grade ores possible (Richter, 1927, pp. 278-81). The consequent positive supply shocks helped to drive down prices, as copper production in Alaska and the South-West of the U.S. surged (Richter, 1927, pp. 278-81).

Insert Figure 4 about here.

The price of copper stayed relatively flat during the 1920s, with a small peak in 1929. According to my analysis, this was due to upward pressure by "other demand shocks" and downward pressure by "supply shocks" that roughly balanced each other out. On the one hand, strong positive "supply shocks" followed the sharp increases in production capacity during the First World War owing to improved mining technology (Radetzki, 2009) and war-time demand. The increased mining capacities were temporarily abandoned in the first few-years after the war in coordinated action by the Copper Export Association.[4] In 1917 world refined production totaled 1.4 million metric tons. It slumped to 0.5 million metric tons in 1921, but then rebounded to 1.3 million metric tons in 1923, after the cartel operation ceased. From 1927 to 1929 production leapt again (for the aforementioned data see U.S. Geological Survey, 2011a). On the other hand, there were strong positive "other demand shocks" that put upward pressure on the price of copper owing to the build-up of inventories and price manipulations by two cartels: the Copper Export Association in the early 1920s and later by the Copper Exporters Inc. (Herfindahl, 1959, pp. 93-4 and 100-6).

[4]Please note that I have not included the three years after the First and Second World Wars in my regressions such that this period is not visible in the figures.

The Great Depression that began in 1929 caused a major negative "world output-driven demand shock" that drove down the price of copper. In response, the Copper Exporters Inc. cartel, which controlled about 85 percent of world output, succeeded in firmly restricting copper production by taking collective action (Herfindahl, 1959, pp. 100-6). This resulted in strong accumulated effects of "supply shocks" that counterbalanced the "world output-driven demand shocks" to some extent. However, diverging interests and declining discipline among its members brought Copper Exporters Inc. to an end in 1932, and world copper production rebounded (Herfindahl, 1959, p. 105). In 1935 the International Copper Cartel emerged and succeeded in driving up the price of copper in the late 1930s (Herfindahl, 1959, p. 110), as the cumulative effects of "other demand shocks" reveal.

From the end of the Second World War until the mid 1970s, the price of copper rose sharply, with peaks in 1955, 1966, 1969, and 1974. During this time post-war reconstruction and the economic rise of Japan generated strong, positive "world output-driven demand shocks", which mainly determined price fluctuations. Interventions by the U.S. government in the form of price controls, import and export restrictions, and government stockpiling were quite common in this period (see Herfindahl, 1959; Sachs, 1999) and are largely reflected in "other demand shocks". Their accumulated effect was, however, rather transient and insignificant. Voluntary production cutbacks in 1963 and strikes in the U.S. from 1959 to 1960 and 1967 to 1968 explain most of the supply shocks during this period (see Sachs, 1999). The nationalization of mines in Chile, Zambia, and elsewhere in the 1960s, and as well as the attempts by the Intergovernmental Council of Copper Exporting Countries (CIPEC) to limit production in 1975 aggravated the negative "supply shocks" (see Mardones et al., 1985; Sachs, 1999). Overall, the cumulative effects of "supply shocks" were rather limited compared to the "world output-driven demand shocks" during this period.

The price of copper reached its peak in 1974. This was due to several kinds of shocks. On the one hand, the CIPEC cartel reduced its exports by fifteen percent (Mikesell, 1979, p. 205), as is evident from the strong accumulative effects of "supply shocks" and "other demand shocks". On the other hand, the recession in 1974 caused strong negative "world output-driven demand shocks", which led to a serious decline in the price in 1975, since the CIPEC could not sustain its action. In the following three decades prices fell mainly because of the negative "world output-driven demand shocks" caused by the recession in 1981, the economic impact of the breakup of the U.S.S.R., and the Asian crisis. There were two small peaks in the late 1980s and the mid 1990s due to the interplay of positive “world output-driven demand shocks” and “supply shocks”.

The sharp rise in copper prices from 2003 to 2007 was basically driven by the cumulative effects of large “world output-driven demand shocks” due to the booming economy. Supply shocks also played a role. In 2005 and 2006 in particular, global copper mine production grew far less than expected owing to strikes, equipment shortages, and other production problems (U.S. Geological Survey, 2007, 2008).

Since the onset of the Great Recession in 2008 “world output-driven demand shocks” have had a negative effect on the real price of copper. This has been offset by strong “other demand shocks”, which have had a positive effect on price since 2005. These shocks reflect changes in inventories (see data provided by the International Copper Study Group, 2010a, 2012a). However, while consumers’ and producers’ inventories have stayed roughtly constant, inventories at exchanges grew more then fourfold between 2004 and 2010. At the same time, Chinese firms imported significant quantities in 2009 and 2010, but their inventories are not transparent (see U.S. Geological Survey, 2010, 2011b).

Overall, my results indicate that the major fluctuations in the price of copper are mainly driven by “world output-driven demand shocks”. “Supply shocks” and “other demand shocks” also play a pronounced role in determining medium-term swings in price. The narrative evidence suggests that the copper market is characterized by a long history of oligopolistic structures. Recurrently appearing cartels were able to influence prices by both restricting output and by stocking. The evidence points to inventory changes by producer cartels, governments, and in the most recent years by investors as a key driver of “other demand shocks”.

4.2 Lead market

My results show that the fluctuations in the real price of lead have basically been driven by “world output-driven demand shocks” and “other demand shocks”. “Supply shocks” do not play a role. My historical account reveals that the market for lead does not have a strong oligopolistic structure so that supply is quite elastic. This is due to the fact that lead resources are relatively widespread and production takes mainly place in the industrialized countries (BGR, 2007). As a consequence, the formation of cartels to restrict output has not been successful in the history of the lead market.

Figure 5 plots the impulse response functions for lead. An unexpected positive rise in demand due to an increase in world output triggers a persistent and significant positive increase in world GDP and in lead production. Its impact on the real price of lead is positive and significant for a period of about five years, far less than in the cases of copper and tin, but relatively similar to the case of zinc.

Insert Figure 5 about here.

A positive unexpected shock to the supply of lead does not cause a significant change in world GDP, but has a strong, significant, and persistent effect on world production of lead. It has only a slightly positive, but insignificant effect on the real price of lead. This is in contrast to my findings for the copper market, where positive "supply shocks" have a strong and significant effect on price. My explanation for this finding is the different market structure in these markets. Copper production is horizontally more concentrated than that of lead (Rudolf Wolff & Co Lt., 1987; BGR, 2007). In addition, copper tends to be mined in developing countries, while lead is mined mainly in industrialized countries which also use lead as a input to manufacturing (Rudolf Wolff & Co Lt., 1987; Schmitz, 1979; BGR, 2007). As a consequence, shocks to supply, in the form of coordinated production decreases by a cartel, for example, have an impact on the price of copper, but not on the price of lead.

The impulse response functions in Figure 5 show that a positive "other demand shock" has no significant impact on world GDP and on lead production. There is no long-term impact due to my identifying assumptions. However, it has a strong positive effect on the real price of lead, which persists for about ten years.

The historical decomposition in Figure 6 illustrates that the price of lead was driven mainly by "world output-driven demand shocks" and "other demand shocks" in the period considered. Unfortunately, not much is known about the lead market in the 19th century such that a clear attribution of events to the structural shocks as presented in Figure 7 is difficult during this period.

The price rose strongly in the early 1850s reaching a peak in 1853. This increase was driven by a strong positive "other demand shock" and by "positive output-driven demand shocks" as the world economy boomed in the 1850s (see Kindleberger and Aliber, 2011). The prices remained at this level for the next decade. Even though "world output-driven demand shocks" continued to put pressure on the lead price, strong positive "other demand shocks" supported them in the mid-1860s. Unfortunately, I have not been able to find a conclusive explanation for these shocks. In the early 1870s there were strong positive "world output-driven demand shocks", which kept the price on a high level.

From the mid 1870s "world output-driven demand shocks" due to the Long Depression as well as negative "other demand shocks" exerted downward pressure on the price of lead. The price rose sharply in the late 1890s owing to "world output-driven demand shocks", reflecting the booming world economy, but also due to "other demand shocks". The latter might reflect action by producer cartels that where quite common at the time in the lead and zinc mining industry, especially in Germany (Gibson-Jarvie, 1983, p. 73). In 1900 and 1901 the Lead Trust, a large cartel in the U.S., limited its production, and stocks increased so sharply that prices rose for some time (Metallgesellschaft, 1904, p. VIII). This is shown in the large positive "other demand shock" on the price at the time. In 1909 the Metallgesellschaft, which controlled most German and other non-U.S. output, led a successful attempt at market manipulation by creating the Lead Smelters' Association together with the main Belgian and Spanish lead-mining companies (Gibson-Jarvie, 1983). Instead of controlling production, the members agreed to leave the entire marketing of lead to Metallgesellschaft, which then used stocks to withhold lead from the market (Gibson-Jarvie, 1983). The "other demand shocks" show that the Association was relatively successful in driving up prices from 1910 to 1913 (Gibson-Jarvie, 1983). Overall, these ups and downs in cartel action may explain the "other demand shocks" before the First World War.

Insert Figures 6 and 7 about here.

In the inter-war period, prices rose, peaking in 1924 owing to the accumulated effects of "world output-driven demand shocks". However, they came under pressure from strong negative "other demand shocks", probably caused by extensive stockpiling (Gibson-Jarvie, 1983). As a reaction to stocks that "had amassed to an alarming degree" (Gibson-Jarvie, 1983, p. 79), non-U.S. producers established the Lead Producers' Reporting Association in 1931. It attempted to raise prices by both restricting production and stockpiling (Gibson-Jarvie, 1983). As the accumulated effects of "other demand shocks" show, it had a considerable positive impact in the first year, when it partly compensated for the strong negative "world output-driven demand shocks" caused by the Great Depression, but it collapsed when Britain imposed import tariffs in 1932 (Gibson-Jarvie, 1983). This put downward pressure on the price as stocks were dissolved (Gibson-Jarvie, 1983). Besides positive "world output-driven demand shocks", "other demand shocks" drove the market in following years. The latter shocks include actions by goverments to protect their zinc producers with import tariffs and other measures and speculation on the London Metal Exchange (Hughes, 1938; Gibson-Jarvie, 1983).

After the Second World War prices rose sharply, reaching a peak in 1951 due to "world output-driven demand shocks" triggered by postwar reconstruction and due to "other demand shocks". These "other demand shocks" were caused by a number of factors. First, after the Second World War the U.S. passed the Strategic and Critical Materials Stock Piling Act, which led to heavy stockpiling, as can be seen from the sharp rise in the accumulative effects of "other demand shocks", especially during the Korean War (see Mote and den Hartog, 1953, p. 684). In 1951 the U.S. government set a price ceiling (see Bishop and den Hartog, 1954, p. 752). As foreign importers were unwilling to sell their lead at the low mandatory U.S. price and foreign consumers could not absorb the quantities concerned, non-U.S. producers' stocks accumulated, as evident from the positive "other demand shocks". As these stocks were sold on the market in the following two years, they exerted downward pressure on the real price of lead.

From 1961 to 1969 the U.S. government introduced the Lead and Zinc Mining Stabilization Program, which paid subsidies to mining companies when prices dropped below a certain threshhold (Smith, 1999). This kept prices fairly stable over this period (Smith, 1999). From 1971 to 1973 the U.S. government imposed price limits, which were lifted in 1973 and then sharply increased the price of lead (Smith, 1999), which was followed by a strong negative "other demand shock" due to de-stocking. The price peak in 1979 was attributable mainly to a worldwide shortage of lead concentrates and heavy demand from centrally planned economies countries (Smith, 1999). However, my analysis suggests that it was this heavy demand from centrally planned economies and "other demand shocks" that drove the price up rather than supply shortages. There were major increases in consumers' and producers' stocks of refined lead (see data provided by U.S. Geological Survey, 2011a) that may have been captured by "other demand shocks".

The 1980s saw strong downward pressure on the price of lead owing to the recession in

1981, as evident from the accumulated effects of “world output-driven demand shocks”, and due to the phasing out of lead from many appliances, which caused strong negative “other demand shocks” (see Smith, 1999). However, demand picked up again in the late 1980s with the growth of the battery industry (Smith, 1999).

From 2003 prices recovered, owing partly to positive “world output-driven demand” until 2007, but largely to positive “other demand shocks” in 2005, 2007, 2009, and 2010. While the positive demand shocks in 2009 and 2010 are attributable to a quadrupling of stocks at commercial exchanges, mainly reflecting demand from institutional investors (see data provided by International Lead and Zinc Study Group, 2011), the strong demand shocks from 2005 to 2007 probably reflect the lead intensive growth in such rapidly industrializing countries as China (Guberman, 2009).

To conclude, fluctuations in the real price of lead have basically been driven by “world output-driven demand shocks” and “other demand shocks” but not by “supply shocks”. Historical evidence shows that the formation of cartels to restrict output has not been successful in the history of the lead market. This is due to the fact that lead resources are relatively widespread and production takes mainly place in the industrialized country (BGR, 2007). “Other demand shocks” have been basically driven by changes in inventories by producers, the U.S. government, and in recent times probably also by investors. “Other demand shocks” also encompass shocks to the use of lead due to environmental regulation in the 1970s and 1980s.

4.3 Tin market

The price of tin has experienced large fluctuations in the past 170 years. According to my results these fluctuations are mainly driven by “world output-driven demand shocks” and “other demand shocks”, but “supply shocks” also play a role. The tin market has been characterized by a long history of oligopolistic structures. Governments have attempted to control the market since after the First World War. There is a strong geographic narrowness of supplies in the Earth’s crust (Gibson-Jarvie, 1983). During history supplies shifted from England, to the Straits and Australia, and then to the South-East Indies (Gibson-Jarvie, 1983). Today, the main mine producers are China, Indonesia, and Peru (U.S. Geological Survey, 2013). ”Tin is unusual among minerals in that the world is dependent on less developed countries for the bulk of its supplies” (Thoburn, 1994, p. 1).

The impulse response functions in Figure 8 reveal that a positive "world output-driven demand shock" exhibits a strong, positive, and persistent effect on world GDP. It causes a positive and significant increase in tin production that lasts for about four years. It triggers a major increase in the real price of tin. The shock continues to persist significantly over a period of more than ten years.

A positive unexpected shock to supply increases GDP slightly for the first three years, but then subsides. It has a strong, significant, and persistent effect on tin production, and a strong and negative effect on the real price of tin that persists significantly for more than fifteen years. This effect is similar to the effect of a copper supply shock on price, but different from the effects on zinc and lead.

Insert Figure 8 about here.

Finally, a positive "other demand shock" has no statistically significant impact on world GDP, but a positive, though rather minor effect on tin production which turns statistically significant about three years after the shock hits. Owing to the long-run restrictions, these effects level off over time. An unexpected increase in "other demand" leads to a strong and positive increase in the real price of tin, which remains statistically significant for more than fifteen years.

Insert Figure 9 about here.

According to the historical decomposition in Figure 9, the fluctuations in the price of tin are mainly driven by "world output-driven demand shocks" and "other demand shocks". The rise in the prices from the 1840s until the late 1850s was due to positive "world output-driven demand shocks", as the world economy boomed in the 1850s (Kindleberger and Aliber, 2011). At the same time, there were unexpected negative "supply shocks" due to partly simultaneous production shortfalls in the main mining areas of Cornwall and Banka, which drove up prices (see data provided by Neumann, 1904, pp. 251-2). "Other demand shocks" also exerted downward pressure on the price, but their sources are not identifiable from the literature.

The price of tin slumped in the following years, reaching a trough in 1867. Britain, whose industry was the main user of tin at that time, lifted the restrictive import policies it had adopted to protect tin producers in Cornwall (Thoburn, 1994), which opened the market to tin from South-East Asia and led to positive "supply shocks" that drove prices down as the structural shocks in Figure 10 show. At the same time, several negative "world output-driven demand shocks" triggered by the Panic of 1857, the American Civil War and the Overend-Gurney crisis exerted downward pressure on the price (see Kindleberger and Aliber, 2011).

In the late 1860s and early 1870s, conflicts between Chinese clans that controlled mining production on the Malayan peninsula turned into war (Thoburn, 1994). Great Britain intervened and took control of important parts of the Malayan peninsula by 1874 (Thoburn, 1994). My analysis suggests that this event triggered major "other demand shocks", since it increased uncertainty in the tin market, which led to a rise in pre-cautionary stock-holding by consumers. The resulting high price resulted in greater production elsewhere. Tin production in Cornwall reached a high in 1871, and Australian production rose significantly in the early 1870s (Thoburn, 1994). This caused positive supply shocks that put downward pressure on the price, which rose even higher after the British consolidated their control of the Malayan peninsula. The result was a significant increase in production and the Malayan peninsula became the most important producer in the world by the late 1870s (Thoburn, 1994). Moreover, the Long Depression in the industrializing world began in 1873 and exerted further downward pressure on the price of tin. Prices recovered from their low levels, reaching a peak in the late 1880s owing to the economic recovery after the Long Depression, which triggered positive "world output-driven demand shocks". From 1889 to the late 1890s prices fell again because of sluggish economic growth and further positive "supply shocks".

Insert Figure 10 about here.

At the end of the 1890s prices rose dramatically. This was due to several factors. First, positive accumulative effects of "world output-driven demand shocks" peaked at the beginning of the 20th century (see also data provided by Crafts et al., 1989; National Bureau of Economic Research, 2010), which led to unexpectedly high rises in the demand for tin. Second, labor shortages and equipment problems caused negative "supply shocks". These problems were also linked to the need to produce tin from deposits of lower ore grades and of greater depths (Thoburn, 1994) and were exacerbated by the decision of local authorities to stop the exploration for new deposits in Kinta Valley, the most important tin-mining area (Thoburn, 1994).

Until the outbreak of the First World War, the price of tin was essentially driven by positive and negative "world output-driven demand shocks" due to the business cycles of the two major economies at the time, the U.S. and the U.K. (see data provided by Crafts et al., 1989; National Bureau of Economic Research, 2010).

Price fluctuations in the inter-war period were mainly influenced by the economic recovery after the First World War, the effects of the Great Depression, and attempts to form cartels. In 1921 the governments of the Federated Malay States and the Dutch East Indies established the Bandoeng Pool and agreed to stabilize the price of tin by jointly managing inventories (Thoburn, 1994). The Bandoeng Pool controlled more than fifty percent of world production at the time (Thoburn, 1994, p. 77). From 1921 to 1923 it withheld some fifteen percent of world tin production from the market and sold it gradually when prices rose in the mid of the 1920s owing to positive "world output-driven demand shocks" (Thoburn, 1994). The action taken by the cartel is evident form the "other demand shocks". The Bandoeng Pool reaped a "substantial profit from the operation" (Thoburn, 1994, p. 77) and was dissolved in 1924 with its stocks exhausted (Baldwin, 1983).

The Great Depression caused strong negative "world output-driven demand shocks" to the price of tin, which coincided with a major expansion of world production (Thoburn, 1994). In response, a number of tin producers tried to withhold tin from the markets by stockpiling it, which explains the positive "other demand shocks" at the time. However, as these attempts were unsuccessful, the International Tin Agreement was drawn up. It encompassed the major producers and introduced formal restrictions on output (Thoburn, 1994). This caused a large negative supply shock in 1932, evident from the accumulative effects of the "supply shocks", which drove the price up again. In 1938 a buffer stock was formed under the International Tin Agreement to stabilize prices (Thoburn, 1994). While the International Tin Agreement inventories were increased in the first year, causing prices to rise, it was soon exhausted in the run-up to the Second World War (Thoburn, 1994).

The high price from the end of the Second World War until the early 1970s was driven mainly by upward pressure from strong "world output-driven demand shocks" and mild "supply shocks". The "world output-driven demand shocks" reflected post-war reconstruction, followed by South-Korea's and Japan's industrial expansion. Downward pressure at that time resulted from "other demand shocks" due to the U.S. stockpiling program. After the Second World War the U.S. passed the Strategic and Critical Minerals Stock Piling Act and bought tin into government inventories because of fears about supplies due to the spread of communism in South-East Asia (Thoburn, 1994). After the Korean War it stopped buying and gradually reduced its inventories during a period of high prices (Smith and Schink, 1976). Purchases from government stocks help to explain the downward pressure on prices by "other demand shocks" until the mid 1950s.

In 1956 the main producing and consuming countries, with the exception of the U.S., concluded a new International Tin Agreement with a view to stabilizing prices. It provided for both export restrictions and an international buffer stock (Thoburn, 1994). It imposed export restrictions, which are visible in the accumulative effects of "supply shocks" until they were lifted in 1960 (Thoburn, 1994). The resulting oversupply is clear from the structural shocks. The buffer stock formed under the International Tin Agreement also exerted some influence on the market in this period (see Thoburn, 1994; Smith and Schink, 1976). From an examination of "other demand shocks" it seems that the downward pressure of subsequent releases from the U.S. stockpiling program was offset by the upward pressure of action under the International Tin Agreement during the 1960s.

The recessions of 1974 and the early 1980s caused large negative "world output-driven demand shocks" to the price of tin (Thoburn, 1994). However, the price rose sharply in 1974 and continued at this high level because of action taken under the International Tin Agreement. Export restrictions were imposed, and the buffer stock was increased (Thoburn, 1994). This strategy worked until the famous collapse of the buffer stock and the suspension of the trade of tin on the London Metal Exchange (see Kestenbaum, 1991, for a detailed account). The collapse and dissolution of the buffer stock caused a serious slump in the price of tin, which leveled-off slowly in the 1990s. During this time, the Association of Tin Producing Countries was established and tried to restrict supplies (Thoburn, 1994).

From the beginning of the new millennium until 2010 the price of tin rose sharply as a result of positive "world output-driven demand shocks" caused by the rise of China and, to a far larger extent, by "other demand shocks". This accords with data on inventories at the London Metal Exchange, which more than doubled from 2008 to 2010, according to data released by the BGR, 2013. This reveals the strong part played by inventory changes in the current price hike, and especially in compensating for the negative "world output-driven demand shock" in 2009. These changes have not only been been due to restocking at producers' and consumers' sites, but also, according to industry observers, due to stockpiling by investment funds as attribute (U.S. Geological Survey, 2011b).

Overall, my results provide evidence that fluctuations in the price of tin are mainly driven by "world output-driven demand shocks" and "other demand shocks", but "supply shocks" also play an important role. The tin market is characterized by a long history of oligopolistic structures and continuous attempts to manipulate prices since after the First World War. Cartels were able to do so by restricting output but also by stockpiling. My account shows that "other demand shocks" were mainly driven by government stockpiling programs, the change in stocks of different cartels, and recently by increases in demand for inventories at metal exchanges. A special feature has been the build-up and collapse of the International Tin Agreement, which influenced the price strongly over several decades.

4.4 Zinc market

My results show that "world output-driven demand shocks" and "other demand shocks" are the main drivers of fluctuations in the real price of zinc. As it is the case for lead, zinc is basically produced in industrialized countries and resources are found all across the world. The market is therefore not prone to functioning cartels and does not have an oligopolistic structure (BGR, 2007).

The impulse response functions in Figure 11 show that the behavior of the zinc market is very similar to that of the lead market. An unexpected rise in demand due to an increase in world output causes a strong and persistent increase in zinc production. While the effect on world output is of considerable statistical significance, the effect on zinc production is statistically significant in only the four following years. Later it becomes a borderline case. Its effect on the price of zinc is substantial and continues to be significant for about five years.

Insert Figure 11 about here.

An unexpected increase in zinc supply does not have an effect on world GDP, but has a strong positive impact on zinc production, as expected. It leads to a statistically insignificant fall in the real price of zinc. In this respect, zinc is similar to lead, but different from copper and tin, which are affected by "supply shocks". I attribute this difference to market structures. Copper and tin production are horizontally more concentrated than zinc and lead production (BGR, 2007; Rudolf Wolff & Co Lt., 1987). In addition, copper and tin are generally mined in developing countries, while lead and zinc are mined mainly in industrialized countries, which also use lead and zinc as manufacturing inputs (Rudolf Wolff & Co Lt., 1987; Schmitz, 1979; BGR, 2007). As a consequence, shocks to supply in the form of coordinated production decreases by a cartell, for example, have an impact on copper and tin prices, without affecting the markets of lead and zinc.

A positive "other demand shock" has no impact on world GDP or zinc production. It has an immediate, major, highly significant, and persistent positive effect on the real price of zinc for a period of up to fifteen years.

The price of zinc has been driven mainly by "world output-driven demand shocks" and "other demand shocks" in the course of history as Figure 12 shows. Prices rose sharply in the 1850s and peaked in 1857, driven by the accumulative effects of "positive output-driven demand shocks" as the world economy boomed in the 1850s (see Kindleberger and Aliber, 2011). Prices then slumped due to the accumulative effects of negative "world output-driven demand shocks" caused by the Panic of 1857 and the American Civil War (see Kindleberger and Aliber, 2011). Even though "world output-driven demand shocks" continued to put pressure on zinc prices, strong positive "other demand shocks" supported them in the mid-1860s as the structural shocks in Figure 13 show. Unfortunately, I have not been able to find a conclusive explanation for these shocks. A possible explanation is the Austro-Prussian War of 1866, which may have affected the trade in zinc from the main mining area in Silesia and so caused "precautionary demand" for inventories. I leave it to future research to delve deaper into the history of the zinc market around that time.

Insert Figure 12 about here.

Prices recovered in the early 1870s owing to "world output-driven demand shocks" and then reached a peak in 1875. This peak was mainly driven by market manipulations of U.S. producers, which are evident from the strong positive "other demand shocks" at the time (Jolly, 1997). The high price caused production increases elsewhere, which sent prices down again (Jolly, 1997). The falling prices led to attempts by German producers in 1979 and by a number of other European producers in 1882 to form cartels and to put upwards pressure on prices by limiting production (Jolly, 1997; Cocks and Walters, 1968). These attempts failed, since local production decreases were offset by production elsewhere (Jolly, 1997; Cocks and

Walters, 1968). As a result, negative "other demand shocks" in combination with "world output-driven demand shocks" due to the Long Depression exerted downward pressure on prices, which reached their lowest level in the mid-1880s.

Insert Figure 13 about here.

As a reaction to the low prices in the 1880s, major European producers joined the "first significant international zinc cartel" (Jolly, 1997, p. 116), which accounted for about 85 percent of world production (Jolly, 1997). The accumulative effects of "other demand shocks" show that it succeeded in temporarily increasing the price, which reached a peak in 1890. There were also supply cuts, which are evident from the structural supply shocks, but did not have a major impact on prices, as can be seen from the accumulative effects. However, the cartel lost its power when new production came on to the market in reaction to the high prices (Jolly, 1997). Subsequent destocking inhibited strong negative "other demand shocks" and exerted additional downward pressure on the price.

The price rose sharply in the late 1890s owing to "world output-driven demand shocks", reflecting the booming world economy, but also to "other demand shocks", which may reflect not only growing stocks at smelters but also attempts by U.S. producers to form a trust (Metallgesellschaft, 1904). In the following years, the price was driven mainly by "other demand shocks", possibly reflecting the "cartel mentality" (Cocks and Walters, 1968, p. 16) of the German metal industry at the time. In 1909 another major attempt was made by European producers to form a cartel, known as the Spelter Convention, which drove up prices in the period until the outbreak of the First World War, as can be seen from the accumulated effects of the "other demand shocks" (Jolly, 1997).

In the inter-war period, prices began by falling, then rose to a peak in the mid-1920s, slumped sharply during the Great Depression and did not recover from this low level until the end of the Second World War. My analysis shows the peak in the mid-1920s to be the result of positive "world output-driven demand shocks" due to the booming world economy and "other demand shocks" probably due to industry stockpiling (see data provided by U.S. Geological Survey, 2011a). Positive supply shocks also exerted significant downward pressure on prices. I attribute these to the widespread introduction of flotation extraction and the electrolytic smelting technique, which made zinc production from complex sulphide ores possible (Gupta, 1982). These new techniques increased output especially in such areas outside

Europe as Canada, Australia, Mexico, Rhodesia, and Indochina (Gupta, 1982). As a result, the production of flotation concentrate in the U.S., for example, rose from 34,000 tons in 1921 to 500,000 tons in 1928 (Jolly, 1997, p. 39).

The new competition from outside Europe triggered the formation of the European zinc cartel in 1928, but it was dissolved again in 1929 because of its members' disparate interests (Jolly, 1997; Gupta, 1982). The Great Depression caused a major negative "world output-driven demand shock" in 1930 and sent the price down. In response, the European zinc cartel was revived and imposed a 45 percent cut in production in 1931, raised to 55 percent in the following year (Jolly, 1997). This explains the negative "supply shocks" in these two years. However, the cartel dissolved in 1934, after some participants were found to have produced and sold more than agreed. Problems associated with the treatment of inventories, which began to be released on to the market as "other demand shocks" show, were also not solved (Jolly, 1997; Gupta, 1982). Several attempts to revive the cartel failed, until one known as the International Sheet Zinc Cartel was founded at the end of the 1930s. It had a brief impact on the market, as the "other demand shocks" suggest, but was dissolved as a result of the outbreak of the Second World War (Jolly, 1997).

The high price level from the end of the Second World War until the early 1970s was driven mainly by upward pressure due to strong "world output-driven demand shocks" fuelled by post-war reconstruction and South Korea's and Japan's subsequent industrial expansion. After the Second World War the U.S. passed the Strategic and Critical Minerals Stock Piling Act, which led to heavy government stockpiling, evident from the sharp rise of accumulated "other demand shocks", and drove prices up very sharply (Gupta, 1982, p. 32). The following years were characterized by price controls and by selling from and buying into the U.S. government stockpile. This economic policy had a strong influence on the price in the rest of the world and a rather destabilizing effect (Gupta, 1982, p. 32). It is also apparent from the "other demand shocks". Furthermore, a new informal cartel was founded in 1964, known as the "Zinc Club" (Jolly, 1997, p. 117). The aim of its members, mainly European, Canadian, and Australian zinc companies, was to support the newly introduced European Producer Price and to restrict the influence of the London Metal Exchange (Jolly, 1997). They used inventories as a tool to set the European Producer Price (Jolly, 1997).

In the early 1970s the price of zinc rose dramatically. My analysis shows that this was mainly due to "other demand shocks". The U.S. government imposed a stabilization program in 1971, under which prices were fixed at a low level (Jolly, 1997). After the fixed price was abandoned in 1973, both U.S. producers and the "Zinc Club" raised their prices by more than 225 percent (Gupta, 1982, p. 30). As producers withheld stocks, evident from the strong, accumulated response of the "other demand shocks", the price on the London Metal Exchange also rose sharply. The recession in 1974 had a major negative effect on the price, and as producers were no longer able to support prices, they fell again (Gupta, 1982). The governments of the U.S., Japan, and France helped zinc companies to reduce inventories while the price was low by increasing government stocks in 1975 and 1976 (Gupta, 1982). After investigations by the U.S. Department of Justice, the informal "Zinc Club" collapsed in 1976 (Jolly, 1997).

The price of zinc peaked in the mid and late 1980s. Both peaks can be ascribed to a combination of positive "world output-driven demand shocks" due to unexpected expansions in the world economy (U.S. Geological Survey, 2011a) and "other demand shocks". I attribute these "other demand shocks" to the introduction of the zinc penny by the U.S. government (Jolly, 1997). This led to irregular purchases of zinc by the U.S. mint, which influenced its price throughout the decade (see Jolly, 1984, 1986, 1989).

In the 1990s the real price of zinc was driven by negative "world output-driven demand shocks" due to the breakup of the U.S.S.R. and the subsequent Asian crisis. The price rise in the early 2000s was fuelled by positive "world output-driven demand shocks" until the Great Recession that began in late 2007 as a result of very strong negative "world output-driven demand shocks". However, strong positive "other demand shocks" partly compensated for these negative shocks. They reflect a major change in warehouse inventories on the London Metal Exchange and the Shanghai Futures Exchange, which increased eightfold and sixfold respectively in the period from 2007 to 2010 (International Lead and Zinc Study Group, 2011). Interestingly, data on inventories held by consumers' and producers' sites did not increase in the same period (International Lead and Zinc Study Group, 2011), which is an indication of the role of institutional investors in the purchase of inventories.

Overall, the price of zinc was mainly driven by "world output-driven demand shocks" and "other demand shocks" over the course of history. Cartels have not had success in restricting output. Historical evidence points to changes in inventories by firms, government, and investors as an interpretation of the "other demand shock".

4.5 Long-term trends

The estimated coefficients of the linear trends in the five estimated VAR models show that prices - with the exception of copper - have basically been trend-less from 1840 to 2010. The negative linear trend is statistically significant at the 5 percent level in the case of the copper price and only statistically significant at the 10 percent level in the cases of the lead and zinc prices. The estimated coefficients for the linear trends in the tin and the crude oil (since 1861) prices are zero.

Insert table 1 about here.

These results are in line with evidence over shorter time periods provided by Krautkraemer (1998), Cynthia-Lin and Wagner (2007) and others, and references therein. They provide long-run evidence for non-increasing non-renewable resource prices under the assumption of a deterministic trend, and contribute to a literature that is certainly not conclusive (see Pindyck, 1999; Lee et al., 2006; Slade, 1982).

5 Sensitivity analysis

I have employed several robustness checks, including an alternative identification scheme, and different time periods and alternative price data to test, whether my main results still hold. To ease comparison, I present the results of forecast error variance decompositions for each of the respective specifications. The respective regression results are available from the author upon request. Table 22 shows the respective contributions of the three shocks to the development of the price for my baseline specification.

In order to check the robustness of the results I compare these to the results of an alternative identification, for which I use Kilian's identification scheme based on short-run restrictions. I postulate a vertical short-run supply curve and no effect of price changes driven by "other demand shocks" on world GDP within the first year. I describe the identification in detail in the Appendix. Even if it is not clear how reasonable the identifying restrictions on annual data are, the empirical results are relatively similar. As table 23 shows, my results stand up with respect to the overall strong impact of demand shocks on the prices of copper, lead, tin, and zinc. However, the effect of supply shocks on the prices of tin and copper do not show up due to the restrictions that I apply regarding the instantaneous impact of world output shocks and other demand shocks on supply.

My results are robust regarding different lag lengths. Table 24 shows that the overall results are relatively similar for using lag lengths of three and six respectively compared to the bench-line case, where I chose the lag lengths according the Akaike Information Criterion.

The empirical results confirm robustness regarding alternative price data. Table 26 illustrates that using the producer price index instead of the consumer price index for disinflation does not lead to major changes in the relative contribution of the shocks to the fluctuations of prices. Employing New York prices instead of London based prices (see Table 27) increases the contribution of supply shocks and reduces the contribution of demand shocks due to unexpected changes in world output significantly in the cases of tin and copper prices. In the cases of the lead and zinc market, "other demand shocks" strongly dominate other shocks. These results illustrate how strong government intervention and stockpiling, the imposing of restrictions on trade policies, and producer prices have dominated non-ferrous metals markets in the U.S. most of the time, whereas the market in London was basically the market-based price setter on a global scale (see also Slade, 1989).

Finally, I check the results for robustness with respect to different sub-periods. Starting the observation period in 1900 or 1925 does not change the general results in the cases of copper, lead, tin, and zinc (see Table 25).

6 The case of crude oil

While the empirical results are quite robust for the four mineral commodities examined above, the results for the crude oil market are less compelling due to structural breaks in the time series. As a comparison, I present the empirical results in the following. The evolution of the variables is presented in Figure 18 in the Appendix.

The structural shocks evolve in a plausible way as Figure 19 in the Appendix shows. "World output-driven demand shocks" develop in a relatively similar fashion as for the other examined mineral commodities. "Supply shocks" are quite pronounced in the time before the First World War and in the interwar period, but have decreased in amplitude after the Second World War. Over the period from 1973 to 2007, the structural shocks are approximately in line with those identified by Kilian (2009).

However, the impulse response functions in Figure 20 in the Appendix raise questions.

A “world output-driven demand shock” has strong negative effects on the real price. This seems to be an anomaly, since it should feature a positive effect. An explanation for this behavior are the strong structural changes in the oil market familiar structural changes in the oil market (see Alquist et al., 2011; Dvir and Rogoff, 2010; Hamilton, 2011). Like in Kilian (2009) a “supply shock” does not have a significant impact on the real price of crude oil. All other impulse response functions behave as expected.

Insert Figure 14 about here.

The historical decomposition in Figure 14 reveals again the problem with regard to the “world output-driven demand shocks”. As expected from the impulse response function, their contribution is turned on its head with a large accumulation of effects of the positive “world output-driven demand shocks” during the Great Depression and a large accumulation of the effects of negative shocks during the 1950s and 1960s. Over the entire period examined, the accumulative effects of “supply shocks” are not important and the accumulative effects of “other demand shocks” make a strong contribution to the real price of crude oil especially during the 1970s as in Kilian (2009). This is in line with the argumentation of Kilian (2009) that the political uncertainty in the Middle East caused a strong increase in the precautionary demand for oil. Overall, the evolution of the accumulative effects of “supply” and “other demand shocks” is plausible over the entire time period examined and in line with the empirical evidence presented by Kilian (2009) for the period from 1973 to 2007.

The results for crude oil are not robust with respect to different sub-periods due to the familiar structural changes in the oil market (see Alquist et al., 2011; Dvir and Rogoff, 2010; Hamilton, 2011). Results for the sub-periods from 1900 to 2010 and from 1925 to 2010, which are presented in Table 25 in the Appendix, reveal that “supply shocks” played an important role in shaping the oil price. However, to study this phenomenon a structural VAR with time varying coefficients would be necessary and I leave this to future research.

7 Conclusion

This paper has examined the dynamic effects of demand and supply shocks on the real prices of copper, lead, tin, zinc, and crude oil over the time period from 1840 to 2010 where possible. Using a historical decomposition based on a structural VAR model with long-term restrictions, my results show that these prices are mainly driven by persistent "world output-driven demand shocks" and "other demand shocks", namely shocks to inventory demand. Supply shocks play a role only in the cases of tin and copper, possibly due to the oligopolistic structure of these markets.

My results contribute to the literature by providing long-term empirical evidence from a new data set on mineral commodity prices. Two major limitations to my analysis may guide further research. First, my model does not include asymmetric responses of prices to positive or negative shocks. This may be particularly important for the effect of positive and negative supply shocks on prices and vice versa. For example, Radetzki (2008) describes an experience which is common in the extractive sector, namely that firms keep their utilization rates high even after negative price and demand shocks hit the market. Second, "other demand shocks" capture all shocks that are orthogonal to "supply shocks" and "world output-driven demand shocks". Disentangling these shocks by explicitly controlling for changes in inventories or the resource intensity of the economy would shed further light on the sources of these shocks.

References

Alquist, R. and Kilian, L. (2010). What do we learn from the price of crude oil futures? *Journal of Applied Econometrics*, 25(4):539–573.

Alquist, R., Kilian, L., and Vigfusson, R. (2011). Forecasting the price of oil. In G., E. and Timmermann, A., editors, *Handbook of Economic Forecasting*, volume 2. CEPR Discussion Paper No. DP8388.

Arrow, K. and Chang, S. (1982). Optimal pricing, use, and exploration of uncertain natural resource stocks. *Journal of Environmental Economics and Management*, 9(1):1–10.

Backman, J. and Fishman, L. (1941). British war-time control of copper, lead, and zinc. *The Quarterly Journal of Economics*, 55(2):210–238.

Baldwin, W. (1983). *The world tin market: political pricing and economic competition.* Duke University Press, Durham, N.C.

Barsky, R. and Kilian, L. (2002). Do we really know that oil caused the great stagflation? A monetary alternative. In *NBER Macroeconomics Annual 2001, Volume 16*, pages 137–198. National Bureau of Economic Research, Inc, MIT Press, Cambridge, M. A.

Barsky, R. and Kilian, L. (2004). Oil and the macroeconomy since the 1970s. *Journal of Economic Perspectives*, 18(4):115–134.

BGR = Federal Institute for Geosciences and Natural Resources (2007). *Rohstoffwirtschaftliche Steckbriefe für Metall- und Nichtmetallrohstoffe.* Federal Institute for Geosciences and Natural Resources (Bundesanstalt fr̈ Geowissenschaften und Rohstoffe), Hanover.

BGR = Federal Institute for Geosciences and Natural Resources (2011). *Price database.* Federal Institute for Geosciences and Natural Resources (Bundesanstalt fr̈ Geowissenschaften und Rohstoffe), Hanover.

BGR = Federal Institute for Geosciences and Natural Resources (2012). *Production database.* Federal Institute for Geosciences and Natural Resources (Bundesanstalt fr̈ Geowissenschaften und Rohstoffe), Hanover.

BGR = Federal Institute for Geosciences and Natural Resources (2013). *Database on LME warehouse stocks.* Federal Institute for Geosciences and Natural Resources (Bundesanstalt fr̈ Geowissenschaften und Rohstoffe), Hanover.

Bishop, O. M. and den Hartog, E. (1954). Lead. In *Minerals yearbook 1951*, pages 738–759. Bureau of Mines, U.S. Government Printing Office, Washington, D.C.

Blanchard, O. and Quah, D. (1989). The dynamic effects of aggregate demand and supply disturbances. *The American Economic Review*, 79(4):655–673.

Bodenstein, M., Guerrieri, L., and Kilian, L. (2012). Monetary policy responses to oil price fluctuations. CEPR Discussion Papers 8928, C.E.P.R. Discussion Papers.

British Petroleum (2011). BP statistical review of world energy. http://www.bp.com/ (accessed on December 20, 2012).

Cafiero, C., Bobenrieth H., E., Bobenrieth H., J., and Wright, B. (2011). The empirical relevance of the competitive storage model. *Journal of Econometrics*, 162(1):44–54.

Cairns, R. and Lasserre, P. (1986). Sectoral supply of minerals of varying quality. *The Scandinavian Journal of Economics*, 88(4):605–626.

Carter, C., Rausser, G., and Smith, A. (2011). Commodity booms and busts. *Annual Review of Resource Economics*, 3:87–118.

Chandler, A. D. (1990). *Scale and scope.* The Belknap Press of Harvard University Press, Cambridge, M.A., and London.

Cleveland, C. and Szostak, R. (2008). Material intensity of use. In Cleveland, C., editor, *The encyclopedia of Earth.* Environmental Information Coalition, National Council for Science and the Environment, Washington, D.C. http://www.eoearth.org/article/Material_intensity_of_use (accessed on November 9, 2010).

Cocks, E. and Walters, B. (1968). *A history of the zinc smelting industry in Britain.* George G. Harrap & Co. Ltd., London.

Crafts, N., Leybourne, S., and Mills, T. (1989). Trends and cycles in British industrial production, 1700-1913. *Journal of the Royal Statistical Society. Series A (Statistics in Society)*, 152(1):43–60.

Cuddington, J. and Jerrett, D. (2008). Super cycles in real metals prices? *IMF Staff Papers*, 55(4):541–565.

Cynthia-Lin, C. and Wagner, G. (2007). Steady-state growth in a Hotelling model of resource extraction. *Journal of Environmental Economics and Management*, 54(1):68–83.

Deaton, A. and Laroque, G. (1996). Competitive storage and commodity price dynamics. *The Journal of Political Economy*, 104(5):896–923.

Dvir, E. and Rogoff, K. (2010). The three epochs of oil. *mimeo*.

Erten, B. and Ocampo, J. (2012). Super-cycles of commodity prices since the mid-nineteenth century. *United Nations Department of Economic and Social Affairs Working Paper*, 2012(110).

Findlay, R. and O'Rourke, K. (2007). *Power and plenty. Trade, war, and the world economy in the second millennium*. Princeton University Press, Princeton.

Fourgeaud, C., Lenclud, B., and Michel, P. (1982). Technological renewal of natural resource stocks. *Journal of Economic Dynamics and Control*, 4(1):1–36.

Frankel, J. and Hardouvelis, G. (1985). Commodity prices, money surprises and fed credibility. *Journal of Money, Credit and Banking*, 17(4):425–438.

Frankel, J. and Rose, A. (2010). Determinants of agricultural and mineral commodity prices. In Fry, R., Jones, C., and Kent, C., editors, *Inflation in an era of relative price shocks*, RBA Annual Conference Volume, pages 9–51. Reserve Bank of Australia, Sydney.

Gibson-Jarvie, R. (1983). *The London Metal Exchange: a commodity market*. Woodhead-Faulkner Ltd., Herts.

Goncalves, S. and Kilian, L. (2004). Bootstrapping autoregressions with conditional heteroskedasticity of unknown form. *Journal of Econometrics*, 123(1):89–120.

Guberman, D. (2009). Lead. In *Minerals yearbook 2007*, pages 42–42.18. U.S. Geological Survey, Reston, V.A.

Gupta, S. (1982). *The world zinc industry*. Lexington Books, Lexington, M.A.

Gustafson, R. (1958a). *Carryover levels for grains: a method for determining amounts that are optimal under specified conditions*, volume 1178. U.S. Dept. of Agriculture, Washington, D.C.

Gustafson, R. (1958b). Implications of recent research on optimal storage rules. *Journal of Farm Economics*, 40(2):290–300.

Hamilton, J. (2008). *The new Palgrave dictionary of economics*, chapter Oil and the Macroeconomy. MacMillan, London.

Hamilton, J. (2011). Historical oil shocks. NBER Working Papers 16790, National Bureau of Economic Research, Inc, Cambridge, M.A.

Hanes, C. (1998). *Business cycles since 1820. New international perspectives from historical evidence. Consistent wholesale price series for the United States, 1860-1990.* Edward Elgar, Cheltenham.

Herfindahl, O. (1959). *Copper costs and prices: 1870-1957.* Published for Resources for the Future by Johns Hopkins Press, Baltimore.

Hotelling, H. (1931). The economics of exhaustible resources. *Journal of Political Economy*, 39(2):137–175.

House of Commons (1853). *Tables of the revenue, population, commerce, &c. of the United Kingdom and its dependencies. Part XXI. 1951.* His Majesty's Stationery Office, London.

House of Commons (1866). *Statistical tables relating to foreign countries. Part X.* His Majesty's Stationery Office, London.

House of Commons (1868). *Statistical tables relating to foreign countries. Part XI.* His Majesty's Stationery Office, London.

Hughes, H. (1938). Lead. In *Minerals yearbook 1937*, pages 919–946. U.S. Geological Survey, Reston, V.A.

IMF = International Monetary Fund (2012). *World Economic Outlook. Growth resuming, dangers remain.* International Monetary Fund, Washington D.C.

International Copper Study Group (2010a). *Copper Bulletin*, volume 17. International Copper Study Group, Lisbon.

International Copper Study Group (2010b). *The world copper factbook 2010.* International Copper Study Group, Lisbon.

International Copper Study Group (2012a). *Copper Bulletin*, volume 19. International Copper Study Group, Lisbon.

International Copper Study Group (2012b). *World refined copper production and usage trends. 2006-2011.* International Copper Study Group, Lisbon.

International Lead and Zinc Study Group (2011). World lead and zinc statistics. *Monthly Bulletin of the International Lead and Zinc Study Group*, 51(12).

Jacks, D., O'Rourke, K., and Williamson, J. (2011). Commodity price volatility and world market integration since 1700. *The Review of Economics and Statistics*, 93(3):800–813.

Jolly, J. (1984). Zinc. In *Minerals yearbook 1983*, pages 919–946. U.S. Geological Survey, Reston, V.A.

Jolly, J. (1986). Zinc. In *Minerals yearbook 1985*, pages 1033–1060. U.S. Geological Survey, Reston, V.A.

Jolly, J. (1989). Zinc. In *Minerals yearbook 1988*, pages 1019–1048. U.S. Geological Survey, Reston, V.A.

Jolly, J. (1997). *US zinc industry: a history, statistics, and glossary.* American Literary Press, Baltimore.

Kestenbaum, R. (1991). *The tin men. A chronicle of crisis.* Metal Bulletin Books Ltd., London.

Kilian, L. (2008a). The economic effects of energy price shocks. *Journal of Economic Literature*, 46(4):871–909.

Kilian, L. (2008b). Exogenous oil supply shocks: how big are they and how much do they matter for the US economy? *The Review of Economics and Statistics*, 90(2):216–240.

Kilian, L. (2009). Not all oil price shocks are alike: disentangling demand and supply shocks in the crude oil market. *American Economic Review*, 99(3):1053–69.

Kilian, L. and Lee, T. (2013). Quantifying the speculative component in the real price of oil: The role of global oil inventories. *Journal of International Money and Finance.*

Kilian, L. and Murphy, D. (2012). The role of inventories and speculative trading in the global market for crude oil. *mimeo.*

Kilian, L. and Murphy, D. P. (2013). The role of inventories and speculative trading in the global market for crude oil. *Journal of Applied Econometrics.*

Kilian, L. and Vigfusson, R. (2011). Non-linearities in the oil price-output relationship. *Macroeconomic Dynamics*, 15(Supplement S3):337–363.

Kindleberger, C. and Aliber, R. (2011). *Manias, panics and crashes: a history of financial crises.* Palgrave Macmillan, Basingstoke.

Klovland, J. (2005). Commodity market integration 1850-1913: evidence from Britain and Germany. *European Review of Economic History*, 9(02):163–197.

Krautkraemer, J. (1998). Nonrenewable resource scarcity. *Journal of Economic Literature*, 36(4):2065–2107.

Labys, W. (2008). *Modeling and Forecasting of Primary Commodity Prices.* Ashgate, Burlington.

Lee, J., List, J., and Strazicich, M. (2006). Non-renewable resource prices: deterministic or stochastic trends? *Journal of Environmental Economics and Management*, 51(3):354–370.

Lütkepohl, H. and Krätzig, M. (2004). *Applied time series econometrics.* Cambridge University Press, Cambridge.

Maddison, A. (2010). Historical statistics of the world economy: 1-2008 AD. http://www.ggdc.net/maddison/ (accessed on June 13, 2011).

Mardones, J., Silva, E., and Martinez, C. (1985). The copper and aluminum industries: a review of structural changes. *Resources Policy*, 11(1):3–16.

Metallgesellschaft (1889). *Statistische Zusammenstellungen über Blei, Kupfer, Zink, Zinn, Silber, Nickel, Aluminium und Quecksilber.* Metallgesellschaft, Frankfurt a.M.

Metallgesellschaft (1901). *Statistische Zusammenstellungen über Blei, Kupfer, Zink, Zinn, Aluminium, Nickel, Quecksilber und Silber. 1891-1900.* Metallgesellschaft, Frankfurt a.M.

Metallgesellschaft (1904). *Statistische Zusammenstellungen über Aluminium, Blei, Kupfer, Zink, Zinn, Kadmium, Magnesium, Nickel, Quecksilber und Silber.* Metallgesellschaft, Frankfurt a.M.

Mikesell, R. (1979). *The world copper industry: structure and economic analysis.* Published for Resources for the Future by John Hopkins University Press, Baltimore and London.

Mitchell, B. (1988). *British historical statistics.* Cambridge University Press, Cambridge.

Mitchell, B. (2003). *International historical statistics: the Americas, 1750–2000.* Palgrave Macmillan, Hampshire, N.Y.

Mitchell, B. (2007). *International historical statistics 1750-2005*, volume 1-3. Palgrave MacMillan, Basingstoke.

Mitraille, S. and Thille, H. (2009). Monopoly behaviour with speculative storage. *Journal of Economic Dynamics and Control*, 33(7):1451–1468.

Mote, R. and den Hartog, E. (1953). Lead. In *Minerals yearbook 1950*, pages 684–707. Bureau of Mines, U.S. Government Printing Office, Washington, D.C.

National Bureau of Economic Research (2010). U.S. business cycle expansions and contractions. http://www.nber.org/cycles.html (accessed September 12, 2010).

Neumann, B. (1904). *Die Metalle. Geschichte, Vorkommen und Gewinnung.* W. Knapp, Halle a.S.

Officer, L. (2013). Exchange rates between the United States Dollar and forty-one currencies. http://www.measuringworth.com/exchangepound (accessed April 05, 2013).

Officer, L. and Williamson, S. (2011). The annual consumer price index for the united states, 1774-2010. http://www.measuringworth.com/uscpi/ (accessed November 2, 2011).

O'Rourke, K. and Williamson, J. (1994). Late nineteenth-century Anglo-American factor-price convergence: were Heckscher and Ohlin right? *The Journal of Economic History*, 54(4):892–916.

Pindyck, R. (1999). The long-run evolution of energy prices. *The Energy Journal*, 20(2):1–28.

Pindyck, R. and Rotemberg, J. (1990). The excess co-movement of commodity prices. *The Economic Journal*, 100(403):1173–1189.

Pindyck, R. S. (1980). Uncertainty and exhaustible resource markets. *The Journal of Political Economy*, pages 1203–1225.

Radetzki, M. (2008). *A handbook of primary commodities in the global economy*. Cambridge Univ. Press, Cambridge, U.K.

Radetzki, M. (2009). Seven thousand years in the service of humanity: the history of copper, the red metal. *Resources Policy*, 34(4):176–184.

Rasmussen, T. and Roitman, A. (2011). Oil shocks in a global perspective: are they really that bad? IMF Working Papers 11/194, International Monetary Fund, Washington D.C.

Richter, F. (1927). The copper-mining industry in the United States, 1845–1925. *The Quarterly Journal of Economics*, 41(2):236–291.

Rudolf Wolff & Co Lt., editor (1987). *Wolff's guide to the London Metal Exchange*. Metal Bulletin Books Ltd., London.

Sachs, J., editor (1999). *Metal prices in the United States through 1998*. U.S. Dept. of the Interior, U.S. Geological Survey, Reston, V.A.

Schmitz, C. (1979). *World non-ferrous metal production and prices 1700-1976*. Frank Cass, London.

Secretary of the Treasury (1864). *Statistics of the domestic commerce of the United States. A resolution of the Senate of the United Statess, March 12, 1863*. Secretary of the Treasury, Washington, D.C.

Slade, M. (1982). Trends in natural-resource commodity prices: an analysis of the time domain. *Journal of Environmental Economics and Management*, 9(2):122–137.

Slade, M. (1989). The two pricing systems for non-ferrous metals. *Resources Policy*, 15(3):209–220.

Slade, M. (1991). Market structure, marketing method, and price instability. *The Quarterly Journal of Economics*, 106(4):1309–1340.

Slade, M. and Thille, H. (2006). Commodity spot prices: an exploratory assessment of market structure and forward-trading effects. *Economica*, 73(290):229–256.

Smith, G. (1999). Lead. In Sachs, J., editor, *Metal prices in the United States through 1998*, pages 73–75. U.S. Dept. of the Interior, U.S. Geological Survey, Reston, V.A.

Smith, G. and Schink, G. (1976). The international tin agreement: a reassessment. *The Economic Journal*, 86(344):715–728.

Stürmer, M. and von Hagen, J. (2012). Der Einfluss des Wirtschaftswachstums aufstrebender Industrienationen auf die Märkte mineralischer Rohstoffe. DERA Rohstoffinformationen 12, Deutsche Rohstoffagentur (DERA) in der Bundesanstalt für Geowissenschaften und Rohstoffe, Berlin.

Svedberg, P. and Tilton, J. (2006). The real, real price of nonrenewable resources: copper 1870-2000. *World Development*, 34(3):501–519.

The Conference Board (2012). *The Conference Board total economy database. Regional aggregates. January 2012.* The Conference Board, New York.

Thoburn, J. (1994). *Tin in the world economy.* Edinburgh University Press, Edinburgh.

U.K. Office of Statistics (2011). Composite price index and annual change 1800 to 2010. http://www.statistics.gov.uk/statbase/TSDdownload1.asp (accessed July 29, 2011).

U.S. Bureau of Labor Statistics (2011). Producer price index: all commodities. http://www.bls.gov/ppi/ (accessed July 29, 2011).

U.S. Bureau of Mines (1883). *Mineral resources of the United States. 1882.* U.S. Bureau of Mines, Washington, D.C.

U.S. Bureau of Mines (1980). *Minerals yearbook. 1978-79. Metals and minerals.* U.S. Bureau of Mines, Washington, D.C.

U.S. Bureau of Mines (1981). *Minerals yearbook. 1980. Metals and minerals.* U.S. Bureau of Mines, Washington, D.C.

U.S. Bureau of Mines (1987). *Minerals yearbook. 1985. Metals and minerals.* U.S. Bureau of Mines, Washington, D.C.

U.S. Bureau of Mines (1993). *Minerals yearbook. 1990. Metals and minerals.* U.S. Bureau of Mines, Washington, D.C.

U.S. Federal Reserve (2011). Industrial production and capacity utilization. Historical data. http://www.federalreserve.gov/ (accessed July 30, 2011).

U.S. Geological Survey (1996). *Minerals yearbook 1995.* U.S. Geological Survey, Reston, V.A.

U.S. Geological Survey (2001). *Minerals yearbook 2000.* U.S. Geological Survey, Reston, V.A.

U.S. Geological Survey (2007). *Minerals yearbook 2005.* U.S. Geological Survey, Reston, V.A.

U.S. Geological Survey (2008). *Minerals yearbook 2006.* U.S. Geological Survey, Reston, V.A.

U.S. Geological Survey (2010). *Minerals yearbook 2009.* U.S. Geological Survey, Reston, V.A.

U.S. Geological Survey (2011a). *Historical statistics for mineral and material commodities in the United States.* U.S. Geological Survey, Reston, V.A.

U.S. Geological Survey (2011b). *Minerals yearbook 2010.* U.S. Geological Survey, Reston, V.A.

U.S. Geological Survey (2013). *Mineral commodity summaries 2013.* U.S. Geological Survey, Reston, V. A.

Wellmer, F. (1992). The concept of lead time. *Minerals Industry International*, 1005.

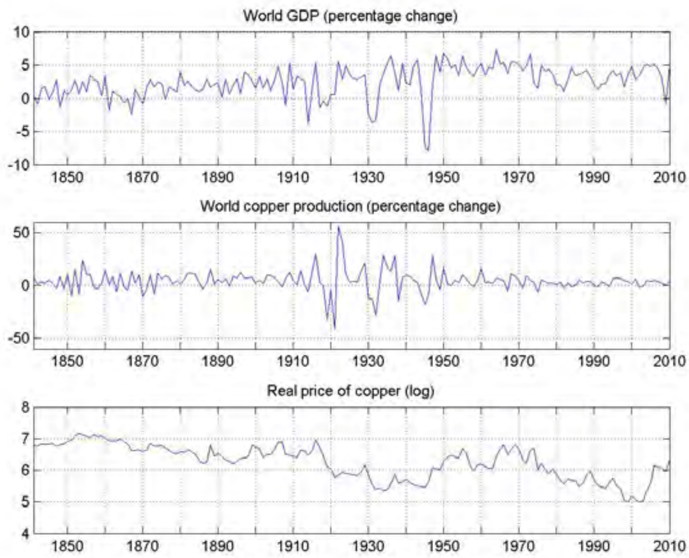
World Bank (2012). World bank database. http://data.worldbank.org/ (accessed January 23, 2012).

World Trade Organization (2010). *World trade report 2010. Trade in natural resources.* World Trade Organization, Geneva.

Wright, B. and Williams, J. (1982). The economic role of commodity storage. *The Economic Journal*, 92(367):596–614.

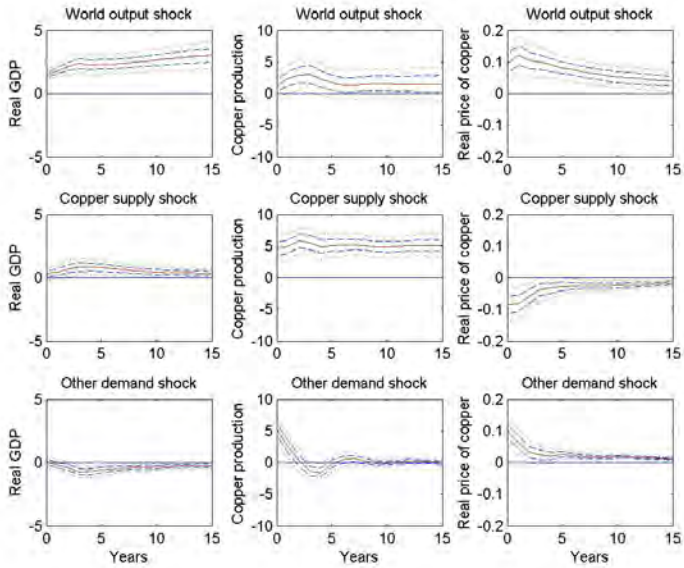
Yergin, D. (2009). *The price. The epic quest for oil, money & power.* Free Press, N.Y.

Appendix 1 Figures and Tables



Notes: For other mineral commodities see the Appendix.

Figure 1: Historical evolution of world GDP, world copper production, and the real price of copper from 1841 to 2010.



Notes: Point estimates with one- and two-standard error bands based on Model (1). I use accumulated impulse response functions for the shocks to world mineral commodity production and world GDP to trace the effects on the level of these variables. For the other mineral commodities see the Appendix.

Figure 2: Impulses to one-standard-deviation structural shocks for copper.

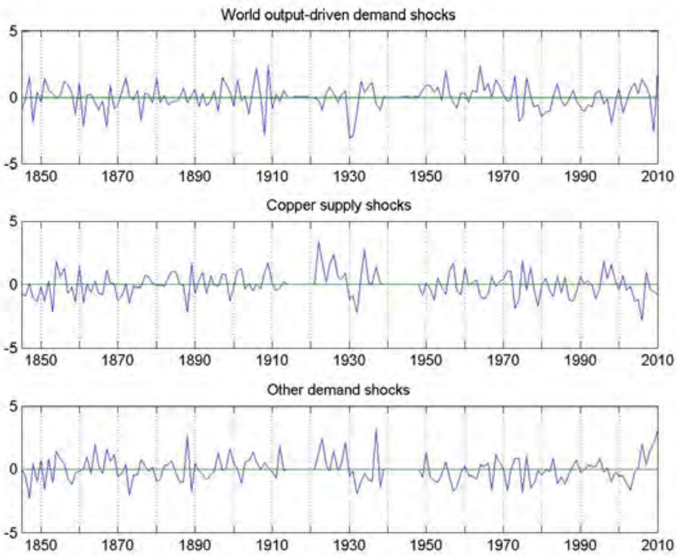
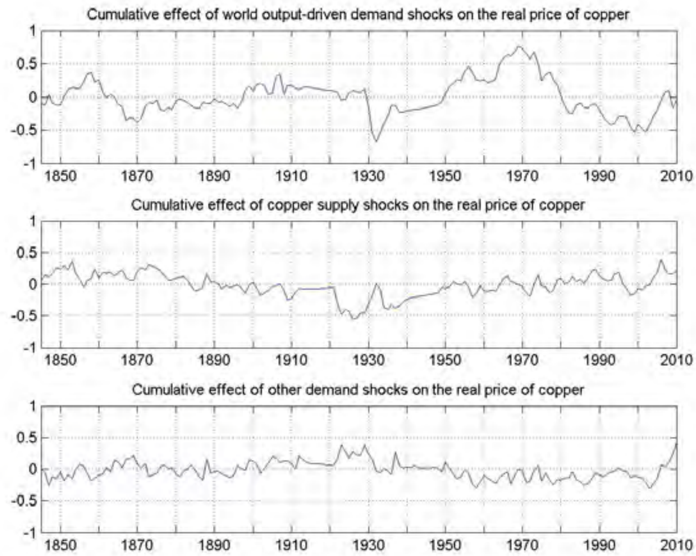
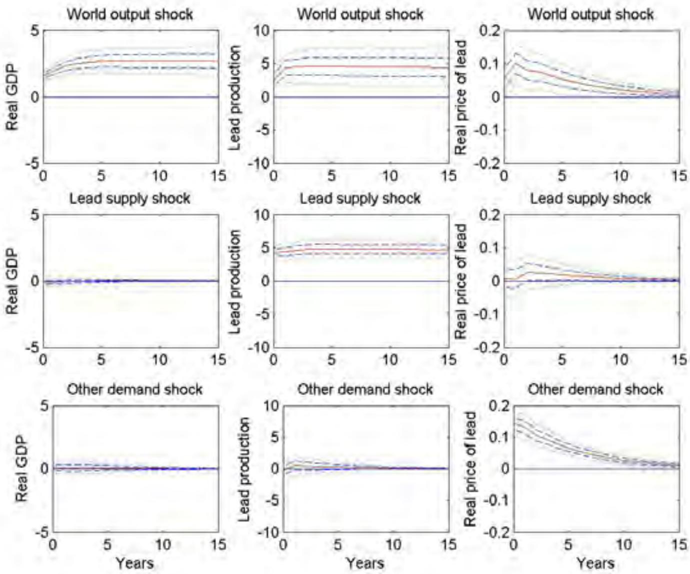


Figure 3: Historical evolution of structural shocks for copper.



Notes: The historical decomposition quantifies the relative contribution of the three specific shocks to the deviation of the actual copper price data from its base projection.

Figure 4: Historical decomposition of the real price of copper.



Notes: Point estimates with one- and two-standard error band based on Model (1). I use accumulated impulse response functions for the shocks on world mineral commodity production and world GDP to trace out the effects on the levels of these variables.

Figure 5: Impulses to one-standard-deviation structural shocks for lead.

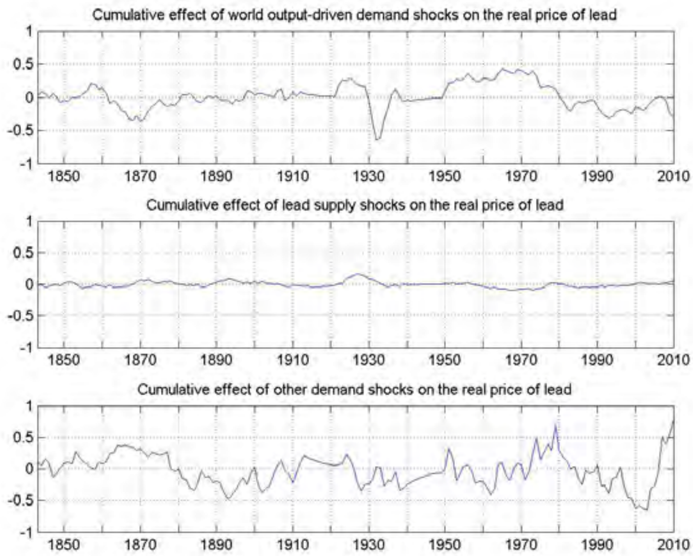


Figure 6: Historical decomposition of the real price of lead.

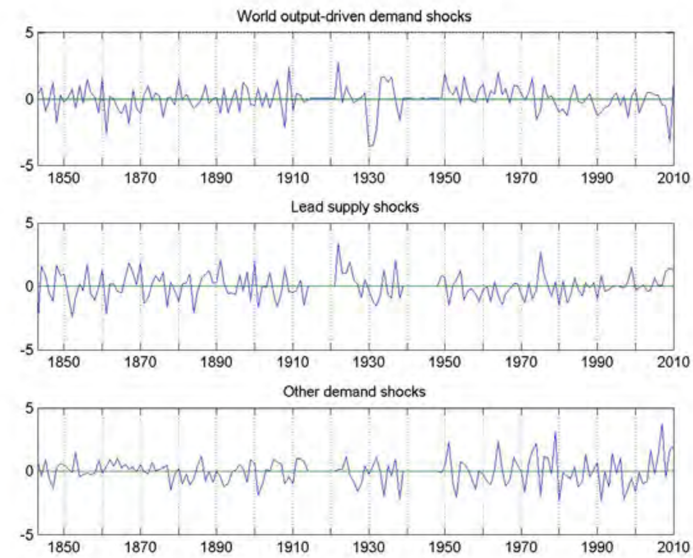
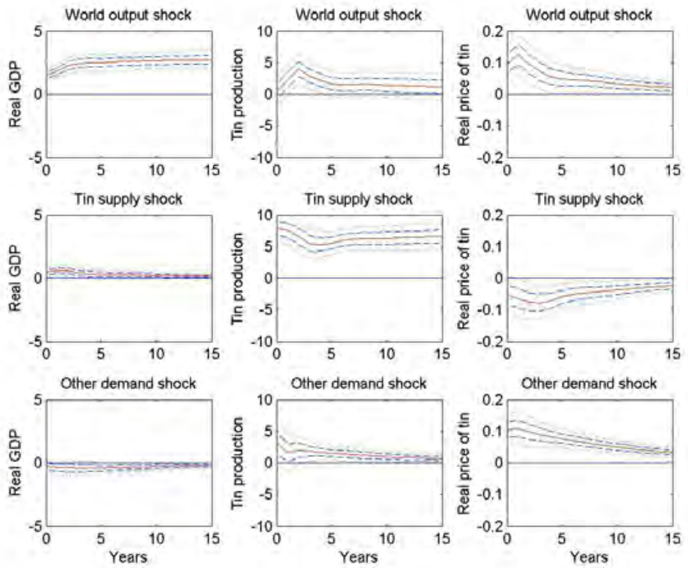


Figure 7: Historical evolution of structural shocks for lead.



Notes: Point estimates with one- and two-standard error bands based on Model (1). I use accumulated impulse response functions for the shocks on world mineral commodity production and world GDP to trace out the effects on the levels of these variables.

Figure 8: Impulses to one-standard-deviation structural shocks for tin.

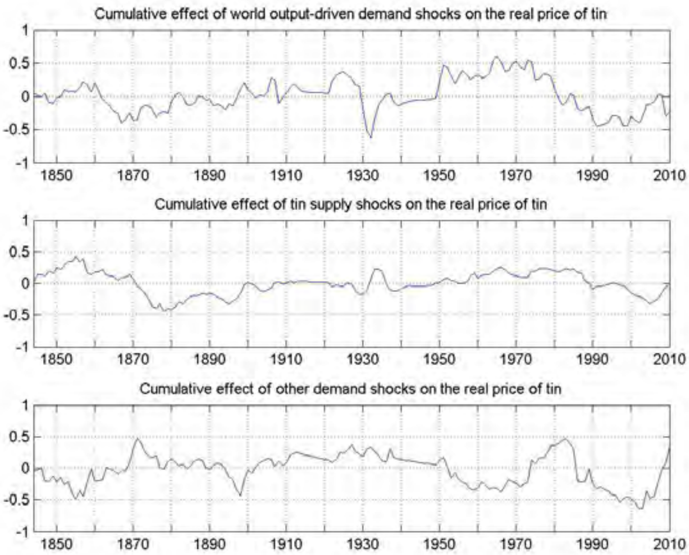


Figure 9: Historical decomposition of the real price of tin.

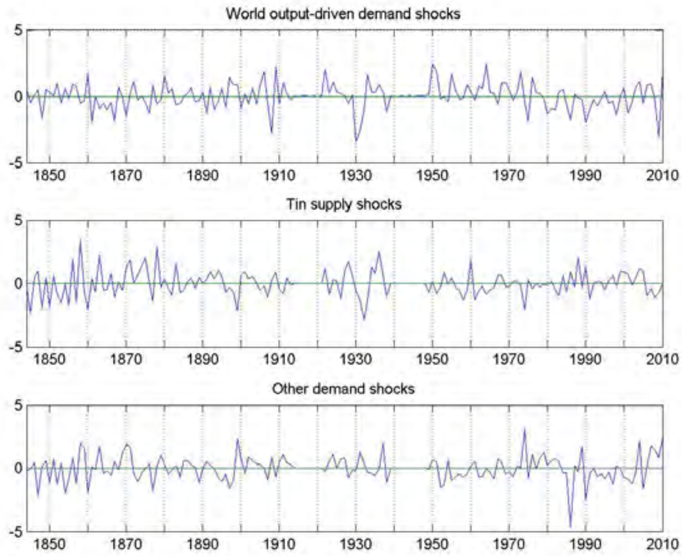
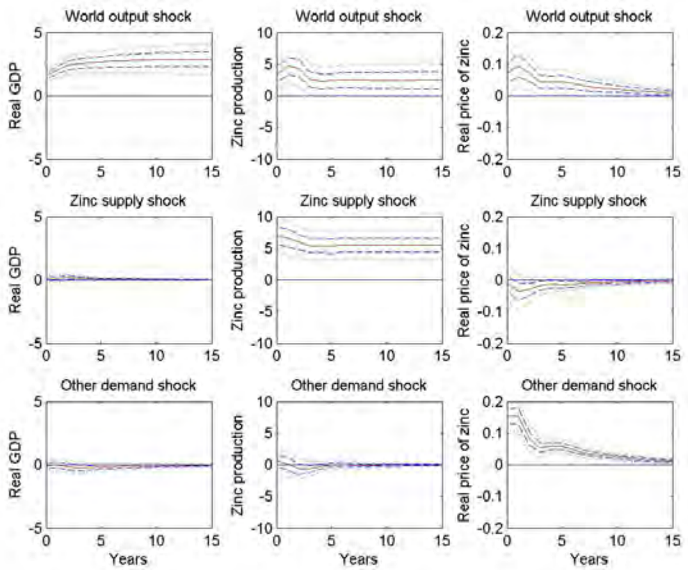


Figure 10: Historical evolution of structural shocks for tin.



Notes: Point estimates with one- and two-standard error bands based on Model (1). I use accumulated impulse response functions for the shocks on world mineral commodity production and world GDP to trace out the effects on the levels of these variables.

Figure 11: Impulses to one-standard-deviation structural shocks for zinc.

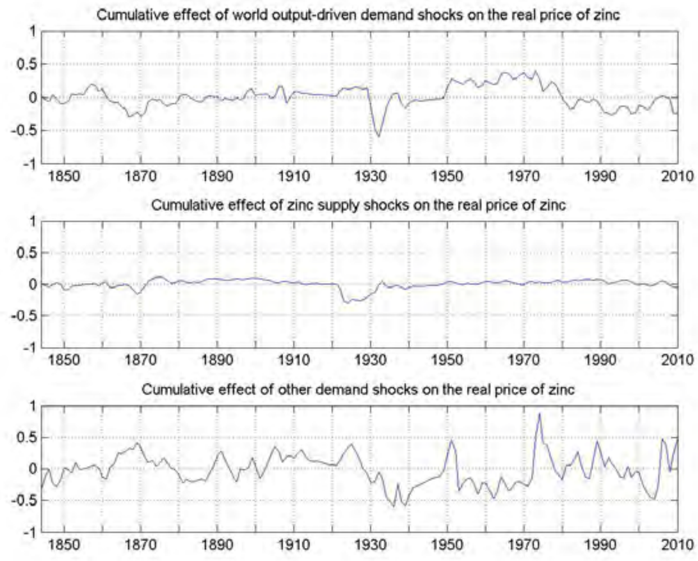


Figure 12: Historical decomposition of the real price of zinc.

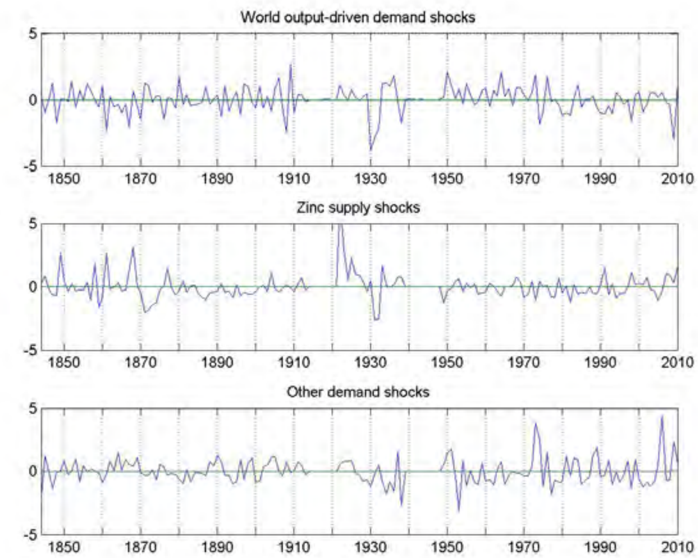


Figure 13: Historical evolution of structural shocks for zinc.

	Est. coefficient	t-stat.	t-prob.
Copper	-0.002	-2.811	0.006
Lead	-0.001	-1.871	0.063
Tin	0.000	0.315	0.753
Zinc	-0.001	-1.777	0.077
Crude Oil	0.001	0.698	0.486

Table 1: Estimated coefficients of the linear trends.

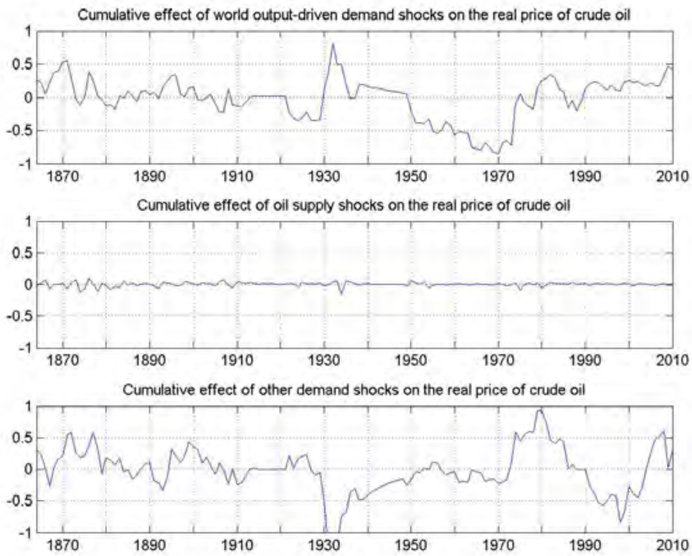


Figure 14: Historical decomposition of the real price of crude oil.

Appendix 2 Data sources

Mineral commodity	Time	Unit	Sources	Notes
Copper	1820-1878	mt	Schmitz 1979, pp. 64-9	Metal content of mined ores.
	1879-1928	mt	Schmitz 1979, pp. 209-13	Smelter production (primary but may also include secondary materials according to a personal communication with Doris Homberg-Heumann of the Federal Institute for Geosciences and Natural Resources).
	1929-1959	mt	Schmitz 1979, pp. 213-25	Refined production; according to a personal communication with Doris Homberg-Heumann from the Federal Institute for Geosciences and Natural Resource the data includes both primary and secondary sources. This is also the case when the data is compared with data from the International Copper Study Group (2010b) from 1960s onwards.
	1960-2005	mt	International Copper Study Group 2010b	Refined production from primary and secondary materials.
	2006-2010	mt	International Copper Study Group 2012b	Refined production from primary and secondary materials.
Lead	1840-1860	mt	Neumann 1904, p. 149-51	Metal content of mine production; missing data for Russia (1841-1844, 1846-1849, 1851-1854, 1856-1859), for Spain (1846-1850, 1853-1857), and for the United Kingdom (1839-1840, 1842-1844) has been completed by using geometric trends.

	1861-2010	mt	BGR, 2012	Metal content of refined production from primary and secondary materials; total production by smelters or refineries of refined lead, including the lead content of antimonial lead, ores, concentrates, lead bullion, lead alloys, mattes, residues, slag, or scrap. Pig lead and lead alloys recovered from secondary materials by remelting alone without undergoing further treatment before reuse are excluded. (See International Lead and Zinc Study Group (2011))
Tin	1821-1883	mt	Neumann 1904, p. 251-3	Tin production.
	1884-2010	mt	BGR, 2012	Primary tin production (smelter)
Zinc	1850-1879	mt	Schmitz 1979, p. 160-6	Mine production.
	1880-1888	mt	Metallgesellschaft 1889, p. 16	Raw zinc.
	1889-1894	mt	Metallgesellschaft 1901, p. 25,	Raw zinc.
	1900-2010	mt	BGR, 2012	Total production by smelters or refineries of zinc in marketable form or used directly for alloying regardless of the type of source material. Remelted zinc and zinc dust are excluded. (See International Lead and Zinc Study Group (2011))
Oil	1961-1964	mt	Mitchell 2007	Crude petroleum (not from oil shales)
	1965-2010	mt	British Petroleum 2011	Includes crude oil, shale oil, oil sands and NGLs (the liquid content of natural gas where this is recovered separately). Excludes liquid fuels from other sources such as biomass and coal derivatives.

Table 2: Data sources for the world production of the mineral commodities.

Mineral Comm.	**Market place**	**Time**	**Units**	**Sources**	**Notes**
Copper	London	1820-1976	£/mt	Schmitz 1979, p. 268-72	1820-1879: Tough copper, fire-refined, av. 99.25% metal cont.; 1880-1914: Best selected copper, fire-refined, av. 99.75% metal cont.; 1915-1976: Electrolytic wirebars, min. 99.9% metal cont.; 1939: Price average Jan-Aug only as LME dealings were suspended; Sep 1940-Aug 1953: controlled selling price of the Ministry of Supply.
	London	1977-2010	US-$/mt	BGR, 2011	Grade A, cash, in LME warehouse, min. 99.99% metal cont.)
	U.S.	1850-1976	US-$/mt	Schmitz 1979, p. 268-72	1850-1899: Lake copper (fire-refined) New York; 1900-1976: electrolytic wirebars, min. 99.9% metal cont., U.S. producer price; Sep 1967-Apr 1968: U.S. copper producer strike, so 1967 is the average of Jan-June and 1968 is the average of May-Dec.
	U.S.	1977-1990	U.S.-$/mt	U.S. Bureau of Mines 1981, 1987, 1993	Cathode, min. 99.99% metal cont., U.S. producer price
	U.S.	1991-2010	U.S.-$/mt	U.S. Geological Survey 1996, 2001, 2007, 2011b	Cathode, min. 99.99% metal cont., U.S. producer price

Lead	London	1820-1976	£/mt	Schmitz 1979, p. 226-37	1820-1886: English pig lead, mostly prices in provincial markets pre-1850, then mainly London prices; 1887-1945: Good soft pig lead; 1946-1976: refined pig, min. 99.97% metal cont.; 1914: Average Jan-July and Nov-Dec only; 1940-Sept 1952: Fixed selling price, Ministry of Supply
	London	1977-2010	U.S.-$/mt	BGR, 2011	Min. 99.97% metal cont., cash, in LME warehouse
	New York	1820-1976	U.S.-$/mt	Schmitz 1979, p. 274-78	1820-1879: Pig lead; 1880-1976: Common grade lead, min. 99.73% metal cont.
	New York	1977-1990	U.S.-$/mt	U.S. Bureau of Mines 1981, 1987, 1993	Min. 99.97% metal cont., North American producer price, delivered.
	New York	1991-2010	U.S.-$/mt	U.S. Geological Survey 1996, 2001, 2007, 2011b	Min. 99.97% metal cont., North American producer price, delivered.
Tin	London	1820-1976	£/mt	Schmitz 1979, p. 240-1	1820-1837: Common refined tin, Cornwall; 1838-1872: Standard tin; 1873-1976: Standard tin, min. 99.75% metal cont.; 1914: Average price of Jan-July and Oct-Dec only; 1942-1949: controlled price, Ministry of Supply.
	London	1977-1978	U.S.-$/mt	U.S. Bureau of Mines 1980, p. 915	Standard tin, min. 99.75% metal cont.
	London	1979-2010	U.S.-$/mt	BGR, 2011	Min. 99.85% metal cont., in LME warehouse, cash.
	New York	1841-1850	U.S.-$/mt	House of Commons 1853,	Computed from quantities and values of imports of tin in blocks and pigs
	New York	1851-1855	U.S.-$/mt		Filled with a linear trend
	New York	1856-1962	U.S.-$/mt	Secretary of the Treasury 1864, p. 46-8	Computed from quantities and values of imports of tin in blocks and pigs.

	New York	1863	U.S.-$/mt	House of Commons 1866, p. 358	Computed from quantities and values of imports of tin in blocks and pigs.
	New York	1864-1865	U.S.-$/mt	House of Commons 1868, p. 378	Computed from quantities and values of imports of tin in blocks and pigs.
	New York	1866-1869	U.S.-$/mt		Filled with a linear trend.
	New York	1870-1976	U.S.-$/mt	Schmitz 1979, p. 293-8	1869-80: Block tin; 1881-1919: Ordinary brands, min. 99% metal cont.; 1920-76: Straits tin, Grade A, min. 99.85% metal cont.; 1918 = median price; 1976 = average January, July, and December only.
	New York	1977-1990	U.S.-$/mt	U.S. Bureau of Mines 1981, 1987, 1993	Contained tin, New York market price, average.
	New York	1991-2010	U.S.-$/mt	U.S. Geological Survey 1996, 2001, 2007, 2011b	Contained tin, New York market price, average.
Zinc	London	1823-1976	£/mt	Schmitz 1979, p. 299-303	1823-1951: Ordinary brands zinc; 1940-1944: controlled price, U.K. Ministry of Supply; 1952-1976: virgin zinc, min. 98% metal cont.
	London	1977-1978	U.S.-$/mt	U.S. Bureau of Mines 1980, p. 981	Prime Western grade, min. 98% metal cont.
	London	1979-2010	U.S.-$/mt	BGR, 2011	Special high grade, min. 99.995% metal cont., cash, LME warehouse
	New York	1872-1874	U.S.-$/mt	U.S. Bureau of Mines 1883	Import price of zinc in blocks or pigs.
	New York	1875-1976	U.S.-$/mt	Schmitz 1979, p. 300-3	1875-1899: Prime Western, min. 98% metal cont.; 1900-1976: Prime Western, Saint Louis, min. 98% metal cont.
	New York	1977-1990	U.S.-$/mt	U.S. Bureau of Mines 1981, 1987, 1993	1977-79: Prime Western, delivered, min. 98% metal cont.; 1980-90: High grade, min. 99.9% metal cont., delivered.

	New York	1991-2010	U.S.-$/mt	U.S. Geological Survey 1996, 2001, 2007, 2011b	Special high grade, delivered, min. 99.99% metal cont.
Crude Oil	U.S./U.K.	1861-2010	U.S.-$/barrel	British Petroleum 2011	1861-1944: U.S. average; 1945-1983: Arabian Light posted at Ras-Tanura; 1984-2010: Brent dated.

Table 3: Data sources for the world mineral commodity prices.

Currencies	**Time**	**Unit**	**Source**
U.S.-$ - British £	1820-2010	British £per U.S.-$	Officer 2013

Table 4: Data sources for the exchange rates.

Index	**Country**	**Time**	**Unit**	**Source**	**Notes**
PPI	U.K.	1820-1913	2005=100	Mitchell 1988, p. 722-4	Rousseaux price index constructed from wholesale prices and unit-value of imports of vegetable, animal, agricultural, and industrial products.
	U.K.	1914-1959	2005=100	Mitchell 1988, p. 725-7	Sauerbeck-Statist price index constructed from wholesale prices and unit-value of food (vegetable and animnal) and raw materials (minerals, textile fibres, sundry).
	U.K.	1960-2010	2005=100	World Bank 2012	Wholesale Price Index
	U.S.	1850-1859	1982=100	Mitchell 2003, p. 702	Wholesale Price Index
	U.S.	1860-1912	1982=100	Hanes 1998	Wholesale Price Index
	U.S.	1913-2010	1982=100	U.S. Bureau of Labor Statistics 2011	Producer Price Index: All commodities
CPI	U.K.	1820-2010	Jan 1974=100	U.K. Office of Statistics 2011	Composite price index
	U.S.	1774-2008	1982-1984=100	Officer and Williamson 2011	Consumer price index

Table 5: Data sources for the price indices.

Time Period	**Unit**	**Source**	**Notes**
1820-2008	Million 1990 International Geary-Khamis dollars	Maddison 2010	Description of data in Maddison, 2010
2009-2010	Million 1990 International Geary-Khamis dollars	The Conference Board 2012	Computed from growth rates of real GDP (PPP adjusted)

Table 6: Data sources for world GDP.

Appendix 3 Data: additional figures

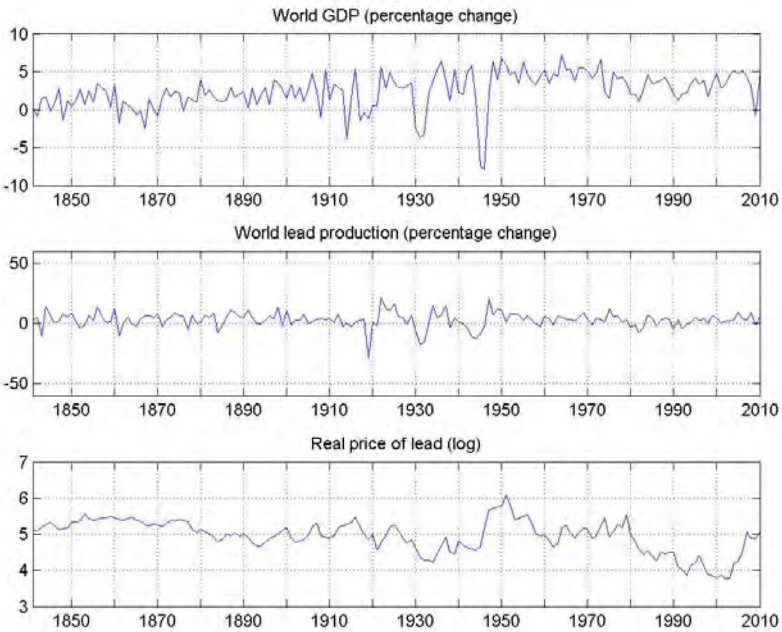


Figure 15: Historical evolution of world GDP, world lead production, and the real price of lead from 1841 to 2010.

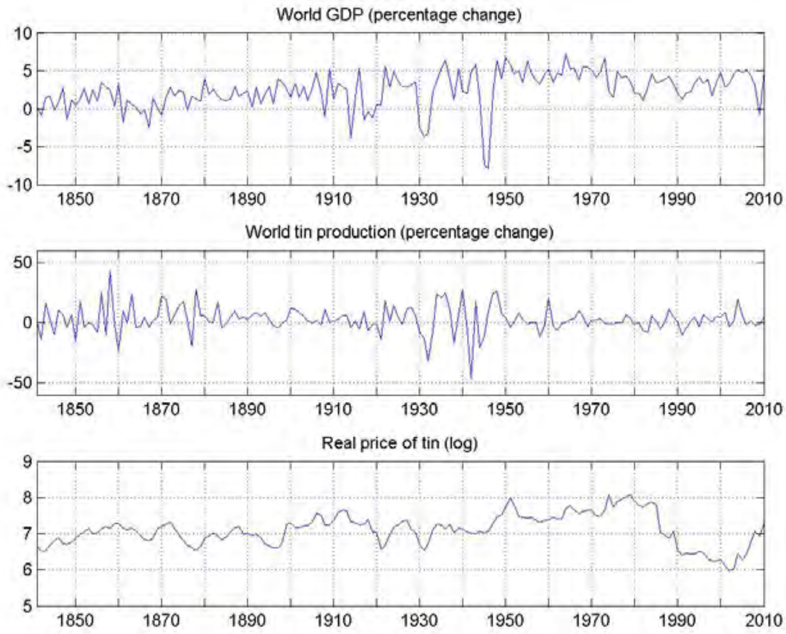


Figure 16: Historical evolution of world GDP, world tin production, and the real price of tin from 1841 to 2010.

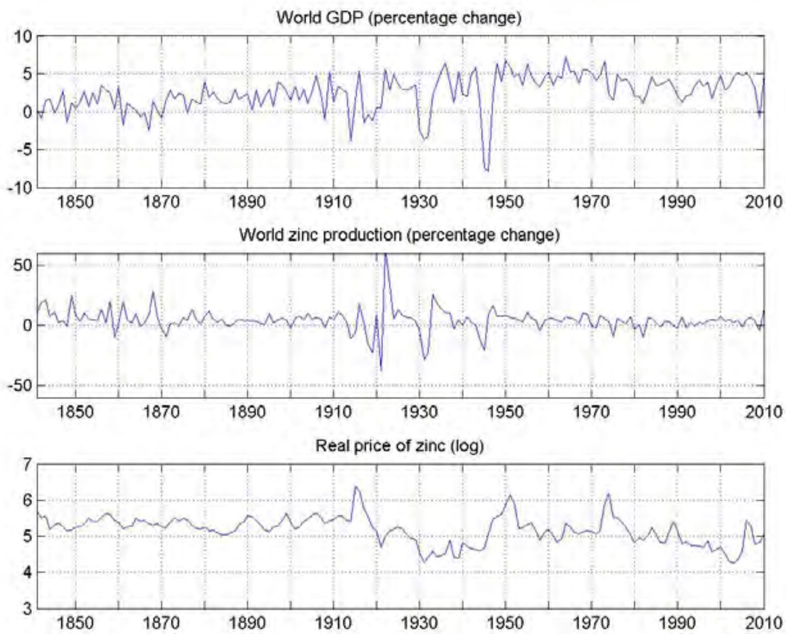


Figure 17: Historical evolution of world GDP, world zinc production, and the real price of zinc from 1841 to 2010.

Appendix 4 Regression results: tables

Indep. variable	Coefficient	t-statistic	t-probability
Dependent variable: World GDP (percentage change)			
World GDP lag1	0.374	3.963	0.000
World GDP lag2	0.353	3.284	0.001
World GDP lag3	0.149	1.605	0.109
World GDP lag4	-0.196	-2.342	0.019
Production lag1	-0.025	-1.549	0.121
Production lag2	-0.008	-0.515	0.606
Production lag3	-0.035	-2.342	0.019
Production lag4	-0.003	-0.207	0.836
Price lag1	-1.535	-1.655	0.098
Price lag2	-0.554	-0.444	0.657
Price lag3	0.207	0.171	0.865
Price lag4	1.795	2.126	0.033
Constant	1.247	0.336	0.737
Trend	0.005	0.660	0.510
Dependent variable: Copper production (percentage change)			
World GDP lag1	1.949	4.366	0.000
World GDP lag2	1.709	3.361	0.001
World GDP lag3	0.810	1.850	0.064
World GDP lag4	-0.257	-0.650	0.516
Production lag1	-0.287	-3.703	0.000
Production lag2	-0.258	-3.491	0.000
Production lag3	-0.374	-5.245	0.000
Production lag4	-0.245	-3.335	0.001
Price lag1	-13.517	-3.085	0.002
Price lag2	-3.038	-0.515	0.607
Price lag3	3.083	0.538	0.590
Price lag4	4.789	1.200	0.230
Constant	68.961	3.936	0.000
Trend	-0.184	-5.177	0.000
Dependent variable: Price of copper (logs)			
World GDP lag1	0.031	3.021	0.003
World GDP lag2	0.009	0.758	0.449
World GDP lag3	0.011	1.042	0.297
World GDP lag4	-0.002	-0.174	0.862
Production lag1	-0.004	-2.272	0.023
Production lag2	-0.002	-1.115	0.265
Production lag3	-0.001	-0.604	0.546
Production lag4	-0.001	-0.608	0.543
Price lag1	0.852	8.380	0.000
Price lag2	-0.168	-1.277	0.220
Price lag3	0.068	0.515	0.606
Price lag4	0.083	0.899	0.369
Constant	1.138	2.801	0.005
Trend	-0.002	-2.807	0.005

Notes: I choose a lag length of 4 according to the Akaike IC). Sample range: 1845-2012, t=166. The coefficients for the World War periods are available from the author upon request.

Table 7: Estimated coefficients for the copper market.

	World GDP	Production	Price
World GDP	1.533	0.325	0.055
	(6.320)	(0.928)	(0.193)
Production	1.300	4.794	5.495
	(1.687)	(4.324)	(3.878)
Price	0.102	-0.091	0.104
	(1.908)	(-2.948)	(5.066)

Notes: World GDP and production reflect the percentage changes of world GDP and of the annual copper production. Price is the average annual real price of copper in logs. Estimates for the structural version of Model (1). Bootstraped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 8: Estimated contemporaneous impact matrix for the copper market.

	World GDP	Production	Price
World GDP	4.003	0	0
	(2.423)	—	—
Production	1.390	5.504	0
	(0.675)	(3.877)	—
Price	1.745	-0.820	0.633
	(1.713)	(-2.328)	(3.998)

Notes: World GDP and production reflect the percentage changes of world GDP and of the annual copper production. Price is the average annual real price of copper. Estimates for the structural version of Model (1). Bootstraped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 9: Estimated identified long-term impact matrix for the copper market.

	Coefficient	**t-statistic**	**t-probability**
Dependent variable: World GDP (percentage change)			
World GDP lag1	0.265	2.760	0.006
World GDP lag2	0.130	1.287	0.198
Production lag1	0.019	0.665	0.506
Production lag2	0.017	0.649	0.516
Price lag1	-0.460	-0.493	0.622
Price lag2	0.335	0.398	0.691
Constant	1.145	0.508	0.612
Trend	0.011	2.233	0.026
Dependent variable: Lead production (percentage change)			
World GDP lag1	0.958	3.102	0.002
World GDP lag2	-0.457	-1.410	0.159
Production lag1	0.039	0.426	0.670
Production lag2	0.031	0.363	0.717
Price lag1	4.945	1.647	0.099
Price lag2	-4.604	-1.698	0.090
Constant	1.349	0.186	0.853
Trend	-0.013	-0.815	0.415
Dependent variable: Price of lead (logs)			
World GDP lag1	0.031	3.249	0.001
World GDP lag2	-0.021	-2.067	0.039
Production lag1	0.001	0.309	0.757
Production lag2	0.004	1.422	0.155
Price lag1	0.890	9.617	0.000
Price lag2	-0.041	-0.489	0.625
Constant	0.782	3.494	0.000
Trend	-0.001	-1.856	0.063

Notes: The table presents estimated coefficients for the reduced form Model (1) with a lag length of 2 (chosen according to the Akaike Information Criterion). Sample range: 1843-2010, t=168. The coefficients for the World War periods are available from the author upon request.

Table 10: Estimated coefficients for the lead market.

	World GDP	Production	Price
World GDP	1.644	-0.156	0.126
	(6.967)	(-0.830)	(0.396)
Production	2.664	4.603	-0.345
	(3.365)	(6.529)	(-0.335)
Price	0.060	0.008	0.153
	(1.678)	(0.253)	(6.258)

Notes: World GDP and production reflect the percentage changes of world GDP and of the annual lead production. Price is the average annual real price of lead in logs. Estimates for the structural version of Model (1). Bootstraped t-statistic is in brackets. Maximum likelihood estimation, scoring Algorithm (see Amisano and Giannini (1992)).

Table 11: Estimated contemporaneous impact matrix for the lead market.

	World GDP	Production	Price
World GDP	2.844	0	0
	(4.630)	—	—
Production	4.664	5.027	0
	(3.046)	(6.083)	—
Price	0.731	0.210	1.012
	(2.044)	(0.897)	(3.364)

Notes: World GDP and production reflect the percentage changes of world GDP and of the annual lead production. Price is the average annual real price of lead. Estimates for the structural version of Model (1). Bootstrapped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 12: Estimated identified long-term impact matrix for the lead market.

	Coefficient	t-statistic	t-probability
Dependent variable: World GDP (percentage change)			
World GDP lag1	0.285	3.069	0.002
World GDP lag2	0.172	1.751	0.080
World GDP lag3	-0.031	-0.393	0.694
Production lag1	0.001	0.040	0.968
Production lag2	-0.009	-0.620	0.535
Production lag3	-0.027	-1.872	0.061
Price lag1	-0.098	-0.108	0.914
Price lag2	0.892	0.682	0.495
Price lag3	-0.587	-0.690	0.490
Constant	-0.729	-0.302	0.762
Trend	0.011	2.704	0.007
Dependent variable: Tin production (percentage change)			
World GDP lag1	1.671	3.284	0.001
World GDP lag2	0.484	0.898	0.369
World GDP lag3	-1.102	-2.533	0.011
Production lag1	-0.162	-1.943	0.052
Production lag2	-0.144	-1.795	0.073
Production lag3	-0.126	-1.597	0.110
Price lag1	-4.061	-0.812	0.417
Price lag2	12.121	1.692	0.091
Price lag3	-10.227	-2.191	0.028
Constant	20.840	1.576	0.115
Trend	-0.048	-2.217	0.027
Dependent variable: Price of tin (logs)			
World GDP lag1	0.014	1.506	0.132
World GDP lag2	-0.016	-1.680	0.093
World GDP lag3	-0.003	-0.328	0.743
Production lag1	-0.001	-0.988	0.323
Production lag2	-0.002	-1.086	0.277
Production lag3	0.000	-0.311	0.756
Price lag1	1.105	12.245	0.000
Price lag2	-0.230	-1.777	0.076
Price lag3	0.049	0.584	0.559
Constant	0.570	2.389	0.017
Trend	0.000	0.068	0.946

Notes: The table presents estimated coefficients for the reduced form Model (1) with a lag length of 3 (chosen according to the Akaike Information Criterion). Sample range: 1844-2010, t=167. The coefficients for the World War periods are available from the author upon request.

Table 13: Estimated coefficients for the tin market.

	World GDP	Production	Price
World GDP	1.543	0.492	-0.307
	(5.756)	(1.478)	(-0.754)
Production	0.373	8.432	3.233
	(0.292)	(6.646)	(1.288)
Price	0.103	-0.057	0.113
	(2.139)	(-1.428)	(3.963)

Notes: World GDP and production reflect the percentages change of world GDP and of the annual tin production. Price is the average annual real price of tin in logs. Estimates for the structural version of Model (1). Bootstrapped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 14: Estimated contemporaneous impact matrix for the tin market.

	World GDP	Production	Price
World GDP	3.035	0	0
	(3.924)	—	—
Production	0.814	7.537	0
	(0.264)	(4.255)	—
Price	1.110	-1.091	1.492
	(0.970)	(-1.562)	(2.740)

Notes: World GDP and production reflect the percentage changes of world GDP and of the annual tin production. Price is the average annual real price of tin. Estimates for the structural version of Model (1). Bootstrapped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 15: Estimated identified long-term impact matrix for the tin market.

	Coefficient	t-statistic	t-probability
Dependent variable: World GDP (percentage change)			
World GDP lag1	0.340	3.492	0.000
World GDP lag2	0.162	1.601	0.109
World GDP lag3	-0.020	-0.248	0.804
Production lag1	-0.016	-0.937	0.349
Production lag2	0.022	1.317	0.188
Production lag3	-0.027	-1.773	0.076
Price lag1	0.398	0.482	0.630
Price lag2	-1.531	-1.370	0.171
Price lag3	1.191	1.486	0.137
Constant	0.340	0.115	0.909
Trend	0.010	1.966	0.049
Dependent variable: Zinc production (percentage change)			
World GDP lag1	1.266	2.581	0.010
World GDP lag2	-0.078	-0.153	0.878
World GDP lag3	-1.050	-2.528	0.011
Production lag1	-0.083	-0.984	0.325
Production lag2	-0.106	-1.277	0.201
Production lag3	-0.112	-1.441	0.150
Price lag1	-2.811	-0.677	0.499
Price lag2	-2.277	-0.405	0.686
Price lag3	4.365	1.082	0.279
Constant	12.648	0.849	0.396
Trend	-0.035	-1.391	0.164
Dependent variable: Price of zinc (logs)			
World GDP lag1	0.024	2.192	0.028
World GDP lag2	0.003	0.226	0.821
World GDP lag3	-0.008	-0.915	0.360
Production lag1	-0.004	-2.286	0.022
Production lag2	0.000	0.171	0.864
Production lag3	-0.001	-0.589	0.556
Price lag1	1.029	11.324	0.000
Price lag2	-0.514	-4.172	0.000
Price lag3	0.331	3.529	0.000
Constant	0.953	2.926	0.003
Trend	-0.001	-1.847	0.065

Notes: The table presents estimated coefficients for the reduced form Model (1) with a lag length of 3 (chosen according to the Akaike Information Criterion). Sample range: 1844-2010, t=167. The coefficients for the World War periods are available from the author upon request

Table 16: Estimated coefficients for the zinc market.

	World GDP	Production	Price
World GDP	1.633	0.139	-0.055
	(6.517)	(0.747)	(-0.150)
Production	3.466	7.457	0.681
	(3.260)	(4.808)	(0.392)
Price	0.076	-0.012	0.163
	(1.698)	(-0.312)	(5.252)

Notes: World GDP and production reflect the percentage changes of world GDP and of the annual zinc production. Price is the average annual real price of zinc in logs. Estimates for the structural version of Model (1). Bootstrapped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 17: Estimated contemporaneous impact matrix for the zinc market.

	World GDP	Production	Price
World GDP	3.121	0	0
	(3.934)	—	—
Production	2.615	5.862	0
	(1.764)	(5.022)	—
Price	0.683	-0.234	0.942
	(1.716)	(-1.015)	(3.081)

Notes: World GDP and production reflect the percentage changes of world GDP and of the annual zinc production. Price is the average annual real price of zinc. Estimates for the structural version of Model (1). Bootstrapped t-statistic is in brackets. Maximum likelihood estimation, scoring Aagorithm (see Amisano and Giannini (1992)).

Table 18: Estimated identified long-term impact matrix for the zinc market.

Appendix 5 The case of crude oil: additional figures and regression results

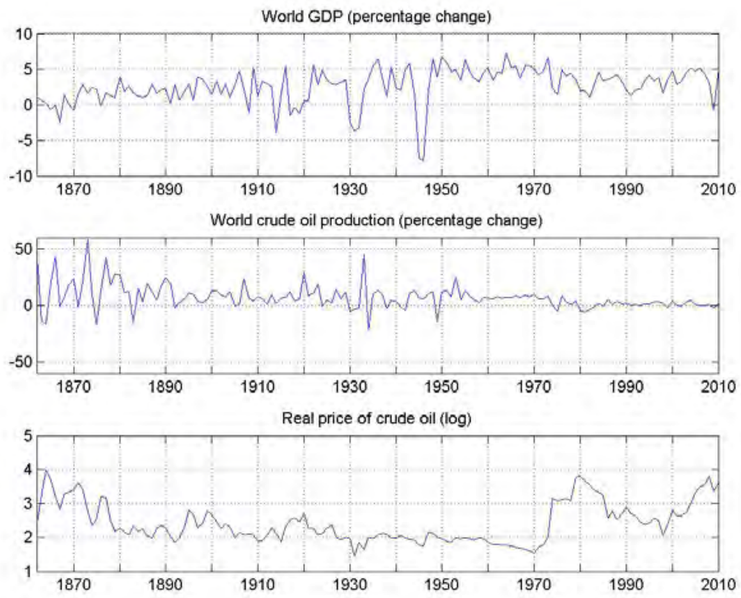


Figure 18: Historical evolution of world GDP, world crude oil production, and the real price of oil from 1862 to 2010.

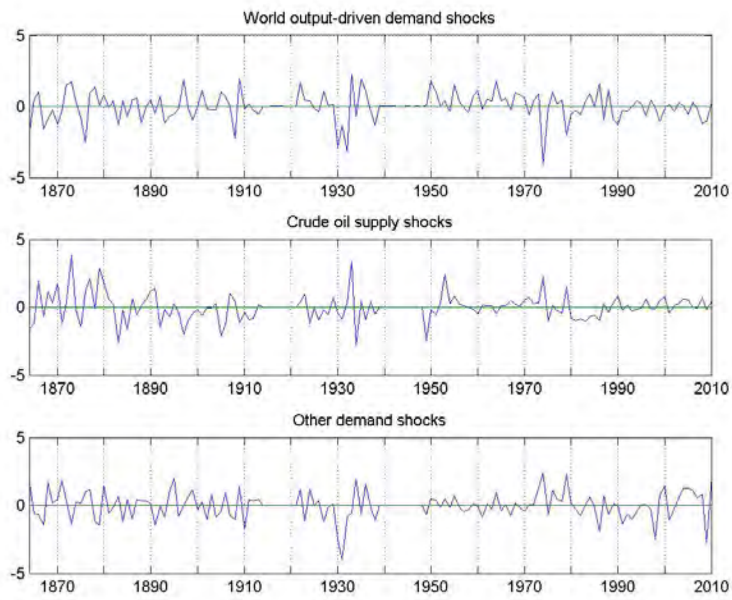
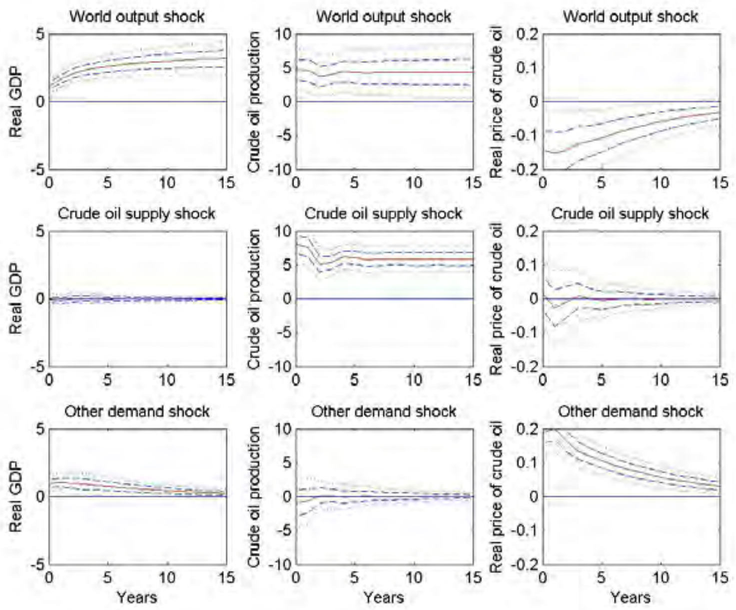


Figure 19: Historical evolution of the structural shocks for crude oil.



Notes: Point estimates with one- and two-standard error band based on Model (1). I use accumulated impulse response functions for the shocks on world mineral commodity production and world GDP to trace out the effects on the level of these variables.

Figure 20: Impulses to one-standard-deviation structural shocks for crude oil.

	Coefficient	**t-statistic**	**t-probability**
Dependent Variable: World GDP (percentage change)			
Variable	Coefficient	t-statistic	t-probability
World GDP lag1	0.317986	3.458524	0.000751
World GDP lag2	0.071221	0.787402	0.432586
Production lag1	-0.007504	-0.497782	0.619541
Production lag2	0.016091	1.200206	0.232404
Price lag1	-1.385274	-2.381678	0.018793
Price lag2	0.820845	1.367192	0.174100
Constant	2.055494	2.562365	0.011623
Trend	0.014000	3.047203	0.002837
Dependent Variable: Crude Oil Production (percentage change)			
World GDP lag1	0.209041	0.365172	0.715620
World GDP lag2	0.431103	0.765509	0.445459
Production lag1	-0.050558	-0.538683	0.591095
Production lag2	-0.311928	-3.736971	0.000286
Price lag1	0.218645	0.060377	0.951955
Price lag2	0.331791	0.088760	0.929420
Constant	17.250599	3.453922	0.000762
Trend	-0.144032	-5.035084	0.000002
Dependent Variable: Price of Crude Oil (logs)			
World GDP lag1	0.010816	0.743631	0.458541
World GDP lag2	-0.016559	-1.157210	0.249466
Production lag1	-0.005225	-2.190927	0.030373
Production lag2	0.002072	0.976797	0.330618
Price lag1	0.992449	10.785610	0.000000
Price lag2	-0.101103	-1.064446	0.289246
Constant	0.267617	2.108760	0.037027
Trend	0.000508	0.698426	0.486251

Notes: World GDP and production reflect the percentage change of world GDP and of the annual crude oil production. Price is the average annual real price of crude oil in logs (CPI deflated). The table presents estimated coefficients for the reduced form Model (1) with a lag length of 2 (according to the Akaike Information Criterion). Sample range: 1864-2010, t=147. The coefficients for the annual dummies during the periods 1914-1921 and 1939-1948 are available from the author upon request.

Table 19: Estimated coefficients for the crude oil market.

	World GDP	Production	Price
World GDP	1.2153	-0.0732	1.0432
	(4.4925)	(-0.2981)	(2.4170)
Production	4.9795	8.5917	-1.0173
	(3.3926)	(5.5415)	(-0.4712)
Price	-0.1541	0.0162	0.2008
	(-2.1241)	(0.3243)	(4.8525)

Notes: World GDP and production reflect the percentage change of world GDP and of the annual crude oil production. Price is the average annual real price of crude oil. Estimates for the structural version of Model (1). Bootstrapped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 20: Estimated contemporaneous impact matrix for the crude oil market.

	World GDP	Production	Price
World GDP	3.6707	0	0
	(3.4743)	—	—
Production	4.6732	6.2922	0
	(1.7918)	(6.4412)	—
Price	-1.7479	-0.0339	1.8482
	(-1.4078)	(-0.0794)	(2.9159)

Notes: World GDP and production reflect the percentage change of world GDP and of the annual crude oil production. Price is the average annual real price of crude oil. Estimates for the structural version of Model (1). Bootstrapped t-statistic is in brackets. Maximum likelihood estimation, scoring algorithm (see Amisano and Giannini (1992)).

Table 21: Estimated identified long-term impact matrix for the crude oil market.

Appendix 6 An alternative identification

As a robustness check and to ease comparison, I provide an identification scheme using a structural VAR model with short-run restrictions following Kilian (2009). He identifies three different types shocks to the real price of crude oil, namely “oil supply shocks”, “aggregate demand shocks” and “oil-specific demand shocks”.

The vector of endogenous variables is $z_t = (\Delta Q_t, \Delta Y_t, P_t)^T$, where ΔQ_t denotes the percentage change in world production of the respective mineral commodity, ΔY_t refers to the percentage change in world GDP, and P_t is the log of the real price of the respective commodity. D_t denotes The deterministic term D_t consists of a constant, a linear trend, and annual dummies during the World War I and II periods and the three consecutive years. The structural VAR representation is

$$Az_t = \Gamma_1 z_{t-1} + ... + \Gamma_p z_{t-p} + \Pi D_t + \epsilon_t \ . \tag{2}$$

Assuming that A^{-1} has a recursive structure, I decompose the reduced-form structural errors e_t according to $e_t = A^{-1}\epsilon_t$, where ϵ_t is a vector of serially and mutually uncorrelated structural shocks:

$$e_t \equiv \begin{bmatrix} e_t^Q \\ e_t^Y \\ e_t^P \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ a_{21} & a_{22} & 0 \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \epsilon_t^Q \\ \epsilon_t^Y \\ \epsilon_t^P \end{bmatrix} \ .$$

I employ the same restrictions on the short-term relations as Kilian (2009). Since he uses monthly and I use annual data, I discuss the plausibility of the identifying assumptions in the following:

Following Kilian (2009) I define “supply shocks” as unpredictable changes to the global production of the respective mineral commodity. The underlying assumption is a vertical short-run supply curve such that “aggregate demand shocks” and “market-specific demand shocks” lead to instantaneous changes in the price (Kilian, 2009). According to this assumption neither innovations due to “aggregate demand shocks” nor due to “market-specific demand shocks” affect supply within the same year (Kilian, 2009).

Using annual data this assumption is plausible to the extent that firms are rather slow in responding to demand shocks by expanding production capacities. Expanding extraction and first stage processing capacities is highly capital intensive and it takes five or more years before new capacities become operational (Radetzki, 2008; Wellmer, 1992, see). It is contestable whether this assumption is also reasonable with respect to firms responding to demand shocks by increasing capacity utilization. However, like Kilian (2008b) in the case oil, I find utilization rates of close to ninenty percent in U.S.-data for the oil extraction, mining, and primary metals industries from 1967 to 2011 (U.S. Federal Reserve, 2011). In the case of the mining and primary metals industries, maintenance, and repairs make a capacity utilization rate higher than 90 percent also unlikely. I acknowledge the shortcomings of the assumption of a vertical supply curve in the short-run but believe that it is at least to some extent reasonable to use it as a robustness check.

I define “aggregate demand shocks” following Kilian (2009) as shocks to global GDP that cannot be explained by “supply shocks”. Hence, I impose the restriction that price changes driven by “other demand shocks” do not affect global GDP within a year. This assumption is plausible given that Kilian (2009) shows that price increases due to oil market specific demand shocks do not result in a statistically significant decline in the level of U.S. GDP. Furthermore, on a global scale a price increase is only a redistribution of income from importing to exporting countries such that global output should not be affected.

Appendix 7 Sensitivity analysis

Comm.	Model	Time	Market Place	Deflator	Lag length	Forecast error variance decomp. (%) horizon: 1 Y	Q	P	horizon: 5 Y	Q	P	horizon: 10 Y	Q	P
Copper	LR	1841-2010	London	CPI	4	35	28	37	60	23	18	65	20	15
Lead	LR	1841-2010	London	CPI	2	13	0	87	31	2	68	32	2	66
Tin	LR	1841-2010	London	CPI	3	40	12	48	37	21	42	33	23	44
Zinc	LR	1841-2010	London	CPI	3	18	0	82	27	3	70	28	4	68
Cr. Oil	LR	1862-2010	Internat.	CPI	2	37	0	63	41	1	59	43	0	56

Notes: Y = World GDP, Q = Production, P = Price, LR = Long-run restrictions, CPI = Consumer Price Index, Internat. = International. I have chosen the lag lengths according to the Akaike Information Criterion

Table 22: Forecast error variance decomposition for the baseline specification.

Comm.	Model	Time	Market Place	Deflator	Lag length	Forecast error variance decomp. (%)								
						horizon: 1			horizon: 5			horizon: 10		
						Y	**Q**	**P**	**Y**	**Q**	**P**	**Y**	**Q**	**P**
Copper	SR	1841-2010	London	CPI	4	20	4	76	46	2	52	51	2	47
Lead	SR	1841-2010	London	CPI	2	15	3	82	26	11	63	26	13	62
Tin	SR	1841-2010	London	CPI	3	15	0	85	16	3	82	11	4	85
Zinc	SR	1841-2010	London	CPI	3	11	4	85	23	2	75	24	2	74
Cr. Oil	SR	1862-2010	Internat.	CPI	2	2	10	89	2	15	83	1	15	83

Notes: Y = World GDP, Q = Production, P = Price, SR = Short-run restrictions, CPI = Consumer Price Index, Internat. = International. I have chosen the lag lengths according to the Akaike Information Criterion

Table 23: Forecast error variance decomposition for the baseline specification using the alternative identification scheme.

Comm.	Model	Time	Market Place	Deflator	Lag length	Forecast error variance decomp. (%)								
						horizon: 1			horizon: 5			horizon: 10		
						Y	**Q**	**P**	**Y**	**Q**	**P**	**Y**	**Q**	**P**
Copper	LR	1841-2010	London	CPI	3	7	43	50	27	42	31	34	39	27
Lead	LR	1841-2010	London	CPI	3	43	1	76	45	3	53	45	2	53
Tin	LR	1841-2010	London	CPI	3	40	12	48	37	21	42	33	23	44
Zinc	LR	1841-2010	London	CPI	3	18	0	82	27	3	70	28	4	68
Cr. Oil	LR	1862-2010	Internat.	CPI	3	50	3	47	42	4	44	52	5	44
Copper	LR	1841-2010	London	CPI	6	29	21	49	56	20	24	61	19	20
Lead	LR	1841-2010	London	CPI	6	30	0	69	50	2	49	47	4	50
Tin	LR	1841-2010	London	CPI	6	43	18	39	41	29	30	36	32	32
Zinc	LR	1841-2010	London	CPI	6	23	0	77	32	2	65	30	6	64
Cr. Oil	LR	1862-2010	Internat.	CPI	6	63	0	37	66	1	33	63	3	34

Notes: Y = World GDP, Q = Production, P = Price, LR = Long-run restrictions, CPI = Consumer Price Index, Internat. = International. I have chosen the lag lengths according to the Akaike Information Criterion

Table 24: Forecast error variance decomposition for the baseline specification using lag lengths of 3 and 6.

Comm.	Model	Time	Market Place	Deflator	Lag length	Forecast error variance decomp. (%)								
						horizon: 1			horizon: 5			horizon: 10		
						Y	**Q**	**P**	**Y**	**Q**	**P**	**Y**	**Q**	**P**
Copper	LR	1900-2010	London	CPI	4	48	24	27	70	17	13	76	14	10
Lead	LR	1900-2010	London	CPI	2	23	0	77	45	3	51	45	5	50
Tin	LR	1900-2010	London	CPI	3	40	31	28	36	40	23	32	41	27
Zinc	LR	1900-2010	London	CPI	3	33	8	59	43	11	46	44	11	45
Cr. Oil	LR	1900-2010	Internat.	CPI	2	49	33	18	43	34	23	43	34	23
Copper	LR	1925-2010	London	CPI	4	38	6	57	71	5	24	77	4	19
Lead	LR	1925-2010	London	CPI	2	29	7	64	58	8	34	57	9	34
Tin	LR	1925-2010	London	CPI	3	53	26	21	49	33	18	43	34	23
Zinc	LR	1925-2010	London	CPI	3	29	3	68	47	11	42	52	10	38
Cr. Oil	LR	1925-2010	Internat.	CPI	2	45	40	14	38	42	20	40	20	20

Notes: Y = World GDP, Q = Production, P = Price, LR = Long-run restrictions, CPI = Consumer Price Index, Internat. = International. I have chosen the lag lengths according to the Akaike Information Criterion

Table 25: Forecast error variance decomposition for the baseline specification over the periods from 1900 to 2010 and from 1925 to 2010.

Comm.	Model	Time	Market Place	Deflator	Lag length	Forecast error variance decomp. (%) horizon: 1			horizon: 5			horizon: 10		
						Y	**Q**	**P**	**Y**	**Q**	**P**	**Y**	**Q**	**P**
Copper	LR	1841-2010	London	PPI	4	23	17	60	46	18	36	54	16	30
Lead	LR	1841-2010	London	PPI	2	6	1	93	20	3	77	21	4	76
Tin	LR	1841-2010	London	PPI	3	28	15	57	24	27	49	21	29	51
Zinc	LR	1841-2010	London	PPI	3	19	0	91	15	4	82	16	4	80
Cr. Oil	LR	1862-2010	Internat.	PPI	2	51	0	49	54	0	46	56	0	44

Notes: Y = World GDP, Q = Production, P = Price, LR = Long-run restrictions, PPI = Producer Price Index, Internat. = International. I have chosen the lag lengths according to the Akaike Information Criterion

Table 26: Forecast error variance decomposition for the baseline specification using the producer price index instead of the consumer price index to deflate prices.

Comm.	Model	Time	Market Place	Deflator	Lag length	Forecast error variance decomp. (%) horizon: 1			horizon: 5			horizon: 10		
						Y	**Q**	**P**	**Y**	**Q**	**P**	**Y**	**Q**	**P**
Copper	LR	1850-2010	New York	CPI	4	3	38	59	10	50	40	12	47	38
Lead	LR	1841-2010	New York	CPI	2	5	0	95	21	1	78	23	1	75
Tin	LR	1841-2010	New York	CPI	3	15	24	61	20	35	44	18	37	44
Zinc	LR	1872-2010	New York	CPI	3	1	5	94	4	13	83	6	13	81
Cr. Oil	LR	1862-2010	Internat.	CPI	2	51	0	49	54	0	46	56	0	44

Notes: Y = World GDP, Q = Production, P = Price, LR = Long-run restrictions, CPI = Consumer Price Index, Internat. = International. I have chosen the lag lengths according to the Akaike Information Criterion

Table 27: Forecast error variance decomposition for the baseline specification using New York instead of London prices.