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

Martin Stürmer

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Abstract

This paper examines the dynamic effects of demand and supply shocks on mineral commodity prices. It provides empirical insights by using annual data for the copper, lead, tin, and zinc markets from 1840 to 2010. I identify structural shocks by using long-run restrictions and compare these shocks to narrative historical evidence about the respective markets. Long-term price fluctuations are mainly driven by persistent demand shocks. Supply shocks exhibit some importance in the tin and copper markets due to oligopolistic market structures. World output-driven demand shocks have persistent, positive effects on mineral production. Long-term linear trends are statistically insignificant or significantly negative for the examined commodity prices. My results suggest that the current price boom is temporary but not permanent. Commodity exporting countries should prepare for a downswing of prices, while commodity importing countries should not fear for the security of supply of these widely used mineral commodities.

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Bonn, February 2013 Martin Stürmer

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Abbreviations

AKI	Akaike Information Criterion
CIPEC	Intergovernmental Council of Copper Exporting Countries
CPI	Consumer Price Index
BGR	Federal Institute for Geosciences and Natural Resources
GDP	Gross Domestic Product
LME	London Metal Exchange
mt	metric tons
PPI	Producer Price Index
VAR	Vector Autoregressive

1 Introduction

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

However, the 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 so focus on the supply side (Arrow / Chang 1982; Fourgeaud et al. 1982; Cairns / Lasserre 1986). Competitive storage mod-els usually interpret shocks as supply driven, but ultimately leave the source of shocks open. (Gustafson 1958a, b; Wright / Williams 1982; Cafiero et al. 2011). Another strand of literature on the subject stresses the role of storage in the presence of expected supply shortfalls in explaining price fluctuations (Alquist / 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.

What empirical work there is tends to focus on the oil market. According to Kilian (2009) and Kilian and Murphy (2012), fluctuations in the price of oil are driven mainly by demand shocks due to the global business cycle. In contrast, Hamilton (2008) stresses the role of supply shocks as a driver of crude oil prices. Thomas et al. (2010) find that a combination of supply and demand shocks determines the price of oil. Pindyck and Rotemberg (1990) claim that such macroeconomic variables as inflation and money supply help to explain the concurrent movements of various commodity prices. In the same direction, Belke et al. (2012) present empirical evidence that monetary aggregates drive various commodity price indices. Frankel and Rose (2010) find that, while global output and inflation have positive effects on the prices of several agricultural and mineral commodities, they are outstripped by volatility and inventories. Regarding storage models, Deaton and Laroque (1992, 1996) show that supply shocks and storage are not sufficient to explain price fluctuations and autocorrelation of commodity prices. They come to the conclusion that "demand shocks are a more plausible source of price fluctuations than has usually been supposed in the literature" (Deaton / Laroque 1996, 899). Cafiero et al. (2011) use a different estimation methodology and find empirical evidence in favour of the predictions of the empirical storage model.

This paper identifies the dynamic effects of demand and supply shocks on mineral commodity prices from 1840 to 2010. It covers a far longer time period than most previous work, thus allowing me to include a long series of boom and bust in prices. Commodities have always shown greater price volatility than manufactures (Jacks et al. 2011), and booms and busts are not a new phenomenon (see, e.g., Cuddington and Jerrett, 2008). In contrast to Erten and Ocampo (2012), who examine "super-cycles" of a metal price index over the period from 1865 to 2009, I am able to include data on the supply side of the mineral commodity markets examined here and hence to pin-down the contribution of shocks to the fluctuation of prices. In addition, I provide a detailed historical account for each price.

To obtain empirical evidence from such a long time period, I use a new set of annual data which includes prices, world production of copper, lead, tin, zinc, and crude oil, and world

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

GDP. I chose copper, lead, tin, and zinc because they were traded on the London Metal Exchange and its predecessors as fungible and homogeneous goods in an integrated world market over the long period considered here. The four mineral commodities studied exhibit a substantial track record in industrial use and are still among the top twenty-five in value of world production. Hence, these four mineral commodity markets exhibit long-term characteristics that other mineral commodities such as iron ore or coal have only gained in recent times. To ease comparison to the literature, I also present regression results for the crude oil market. In contrast to the other four mineral commodities, the market has undergone major structural changes (Kilian / Vigfusson 2011; Dvir / Rogoff 2010) which make it difficult to obtain regression results that are robust across sub-periods.

I use a structural vector autoregressive (VAR) model to decompose demand and supply shocks to fluctuations in the real price of the commodity concerned. To do so, I assume the existence of three different types of shock to commodity prices: "supply shocks", e.g., a disruption in physical production due to strikes; "world output-driven demand shocks", which include shocks in global demand for all commodities due to, e.g., an unexpected strong growth of world output; and "other demand shocks". The latter include all other shocks that have no correlation with the aforementioned two shocks. I interpret them as mainly capturing unexpected changes in inventories driven by the market power of producers, government stocking programs, and changing expectations of consumers. My identification is based on long-run restrictions, which allows me to leave short-run relationships unrestricted.

My paper is to my knowledge the first to provide long-term evidence on demand and supply shocks in mineral commodity markets. The main conclusion drawn in this paper is that price fluctuations of the four mineral commodities studied here were basically driven by demand shocks rather than by supply shocks over the period from 1840 to 2010. My results point to the importance of models that take into account demand shocks due to world output like in Kilian (2009) and in Kilian and Murphy (2012). Dvir and Rogoff (2010), Mitraille and Thille (2009), Bodenstein and Guerrieri (2011), and others have only recently begun to develop such theoretical models.

My analysis suggests that extensions of the seminal Hotelling (1931) model such as those by Arrow / Chang (1982), Fourgeaud et al. (1982), and Cairns / Lasserre (1986) which explain price fluctuations by supply shocks must be rethought. It also questions the usual interpretation of shocks in competitive storage models (Gustafson 1958a, b; Wright and Williams, 1982), which views supply shocks as a key to explaining commodity price fluctuations. Supply shocks 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 / Thille 2006).

In contrast to the classical competitive storage models, my findings point to inventories as a source of fluctuations rather than a calming agent. My results provide long-term evidence in support of Alquist and Kilian (2010) and others who maintain that storage in the presence of expected supply shortfalls explains price fluctuations. Narrative evidence in this paper, however suggests that shocks due to changes in inventories are rather driven by producer cartels and government stockpiling, and only in recent times by "precautionary" behaviour of consumers or investors in the markets examined here.

Impulse response functions show that "world output-driven demand shocks" have had a large and statistically significant effect on the prices of all the commodities considered, reaching their peak after one or two years. They persist for five to ten years. "Other demand shocks" have direct and significant effects on all commodities and are quite persistent. Supply shocks exhibit a significant impact only on the prices of tin and copper. Whereas world output-driven demand shocks have a strong, significant, persistent and positive effect on the production of copper, lead and tin, they have a positive, but only insignificant effect on the production of zinc.

In contrast to the other mineral commodities examined in this study, the results for 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 / Rogoff, 2010) and the strong change of importance of oil in the economy over time. 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, whereas they 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.

My results have important policy implications both for commodity exporting and commodity importing countries. For optimal fiscal and macroeconomic policy responses in commodity exporting, developing countries, it is important to know first whether a price change is temporary or permanent, and second to identify the driving source behind the price change (see IMF 2012). My results suggest that the current price boom is temporary rather than permanent: the long-term trends are significantly negative or statisti-cally insignificant for the commodities examined. Hence, commodity exporters should take a countercyclical 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 fis-cal 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 market but are ineffective, as history shows, in increasing prices over the long-run.

For countries which import mineral commodities, my results indicate that apprehensions about the security of the supply are rather exaggerated in the light of historical evidence 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, while 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 introduce my interpretation of the shocks studied here. In section 3 I describe the construction of my data set. Section 4 focuses on the econometric model and the scheme used to identify and distinguish the different structural shocks. In sections 5 and 6, I present empirical results and robustness checks for copper, lead, tin, and zinc. Section 7 gives empirical results and robustness checks for the case of crude oil. Section 8 offers conclusions.

2 Interpretation of shocks to mineral commodity prices

I classify the key determinants of mineral commodity prices close to Kilian (2009). This allows me to distinguish three shocks, notably "world output-driven demand shocks", "supply shocks" and "other demand shocks".

I define "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 the world economy. They thus also 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. "World output-driven demand shocks" result from both non-persistent aggregate demand shocks (e.g., monetary policy shocks) and persistent aggregate supply shocks (e.g., productivity changes).

"Supply shocks" are shocks to the production of mineral commodities due to unexpected changes in production caused by cartels, strikes, or natural catastrophes.

I do not directly include "other demand shocks" in this model due to missing long-term data on inventories and world use of the mineral commodities. Instead, controlling for "world output-driven demand shocks" and "supply shocks" allows me to pin down the "other demand shocks" as the residual of a structural dynamic simultaneous-equation model. They mainly reflect changes in the demand for inventories of mineral commodities which stem from three different sources: first, government stocking programs, second, producers with market power who increase their inventories in an attempt to increase prices, and finally, shifts in expectations of the downstream processing industry about the future supply and demand balance (see Kilian 2009; Kilian / Murphy,2012, on the last point).

As "other demand shocks" capture all shocks that are uncorrelated to "world output-driven demand shocks" and "supply shocks", they also include unexpected changes in the intensity of use of the respective mineral commodity in the production of world output. The intensity of use reflects the quantity of a mineral commodity which an economy needs to produce one unit of output. The intensity of use is driven by several factors: first, technical improvements that either decrease or increase the quantity of a mineral commodity used to produce a specific good, second, substitution by other materials, third, changes in the structure of world output (e.g., a higher share of services), fourth, saturation of markets, and finally, government regulations that change the use of materials (for example the phase-out of lead additives in gasoline see (Cleveland / Szostak, 2008). However, all of these processes are rather longterm, especially on the world level. Even government regulation, such as that imposed on lead additives, has become set in a continuous process of phasing-out over several decades. Narrative historical evidence suggests that "other demand shocks" capture unexpected changes in inventories rather than changes in the intensity of use. The latter are rather captured in the linear trends in the regressions.

3 A new data set

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 LME was the principal price setter in these non-ferrous metals markets outside of the U.S. during most of the study period (Schmitz 1979; Rudolf Wolff & Co Lt. 1987; Slade 1991) . The prices are in British-£ for most of the period covered in this study. Since the middle of the 1970s they have been given in U.S.-$, and I have transformed them to British-£ by using annual exchange rates. For robustness checks I have also collected U.S.-American prices. I obtained nominal world market prices for crude oil from British Petroleum (2011). This price series reaches back to 1861. Please note that there have been some gradual changes in the quality of products over time.

Following Krautkraemer (1998) and Svedberg / Tilton (2006), I deflate all nominal prices by the respective consumer price indices (CPI) for the U.K. and the U.S. I also 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.

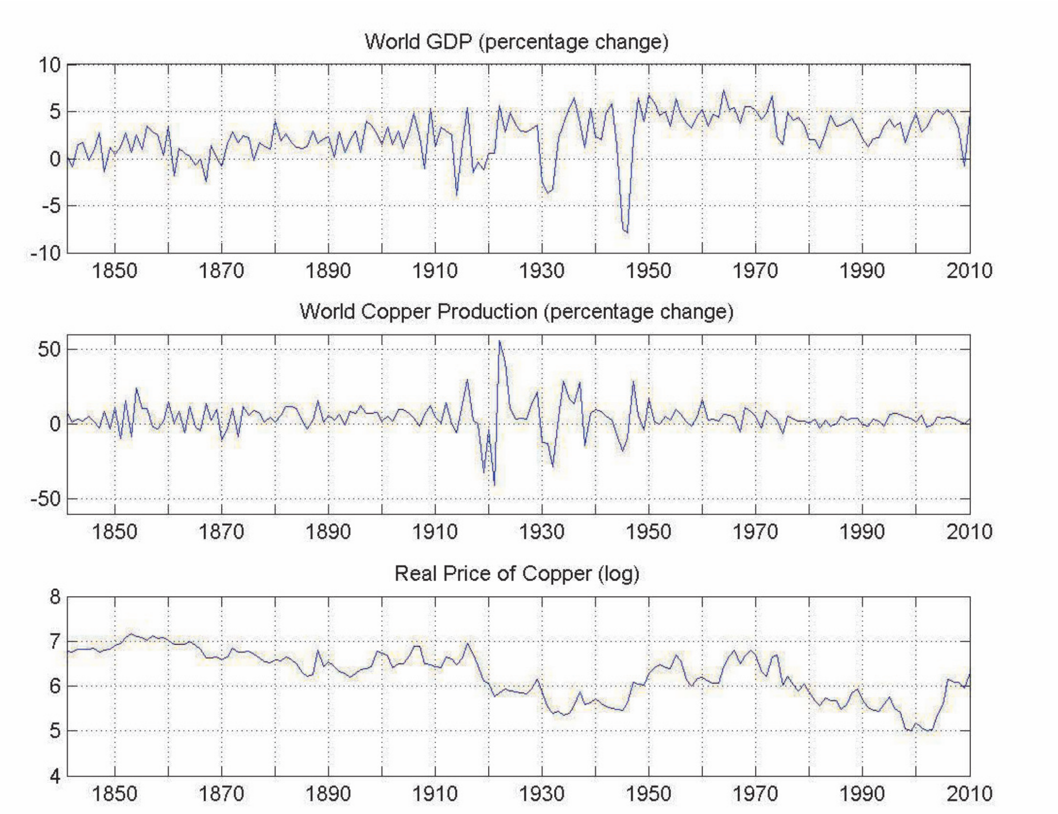
A common definition for the existence of a world market is that prices for a homogeneous good strongly co-move across different areas of the world. This implies that price movements are in accordance with the law of one price, even though the levels of prices might differ due to transportation costs or trade barriers. Klovland (2005) shows that British and German markets for copper, lead, tin, and zinc were integrated from 1850 until World War I, whereas price gaps for pig iron and coal remained quite significant due to trade policies and high transport costs. O'Rourke and Williamson (1994) find a strong convergence of U.S. and British copper and tin prices between 1870 and 1913. Finally, Stürmer and von Hagen (2012) provide evidence from British, U.S., and German price data for copper, tin, and zinc from 1850 to 2010.

Unfortunately, there is to my knowledge no empirical evidence regarding historical integration of the oil market. However, 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. In the 1870s and 1880s it was even the 4th largest U.S. export in value. By the 1880s competition was already strong from Russian oil. Hence, I assume in the following sections that world oil markets have been as integrated over time as the non-ferrous metal ones described above and leave it to future research to find statistical evidence for this assumption.

According to Findlay and O'Rourke (2007), commodity markets disintegrated during World Wars I and II. Price and supply controls for mineral commodities tend to characterize war-time economies (see Backman / Fishman (1941) regarding the example of Great Britain). Unfortunately, no systematic study of price convergence for the above metals in the inter-war period has been carried out. I account for the disintegration of world markets during the two World War periods by using yearly dummies for the war period and the three consecutive years. For the period after World War II until today, Labys (2008) finds evidence for strong market integration.

I have assembled data on the world production of the four 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 secondary materials. However, the differentiation between primary and secondary materials

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



Notes: For other mineral commodities see the Appendix.

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.

In contrast to Kilian (2009) and Kilian and Murphy (2012) I do not create a freight rate index to measure global economic activity but use world GDP from Maddison (2010) and The Conference Board (2012). Unfortunately, Maddison's data set only provides annual world GDP data from 1950 onwards. Therefore, I sum up country based annual data. For those years where country based annual data is missing, I generally interpolate the data with linear trends. For European countries and Western offshoots, I compute their respective shares of output related to neighboring countries, where data is available. I then interpolate these shares and multiply them with the 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.

4 Identification

I use a three-variable, structural VAR model with long-run restrictions to decompose unpredictable changes in the real mineral commodity prices into three mutually uncorrelated shocks, notably "world output-driven demand shocks", "supply shocks", and "other demand shocks". 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, wheras I do so at the level of a specific commodity market.

The basic idea of the variance decomposition is to find what amount of information each variable, notably world total output 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 total output 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 price. D_t denotes a matrix of deterministic terms, notably a constant, a linear trend, and annual dummies during World War I and II periods and the three years immediately after. The structural VAR representation is

$$Az_t = \Gamma_1^* z_{t-1} + ... + \Gamma_p^* z_{t-p} + \Pi^* D_t + B\varepsilon_t \ . \qquad (1)$$

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

To compute the structurally identified impulse responses, I estimate the contemporaneous impact matrix $C = A^{-1}B$ by $\hat{C} = \hat{\Phi}^{-1}\hat{\Psi} = \hat{\Phi}^{-1}\text{chol}[\hat{\Phi}\hat{\Sigma}_u\hat{\Phi}']$. Φ is the matrix of accumulated effects of the impulses, namely $\Phi = \sum_{s=0}^{\infty}\Phi_s = (I_K - \Gamma_1 - ... - \Gamma_p)^{-1}$. Ψ is the long-run impact matrix of structural shocks. We need $K(K-1)/2 = 3$ restrictions 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 mineral commodities and "other demand shocks" exhibit transitory but not permanent effects on world total output. These two shocks thus affect world total output 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 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" (see below) have no long-term effect on global real GDP. This assumption seems strong as one might argue that a reduction in inputs of a certain commodity might affect productivity and hence world total output 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 of relevance. 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 output 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 total world output. 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 global real GDP from the aggregate demand side. Even in the case of crude oil, Rasmussen and Roitman (2011) have shown that oil price shocks on a global scale exhibit only small and transitory negative effects on a slight majority of countries.

I do not distinguish between the different sources of "world output-driven demand shocks", be they transitory aggregate demand shocks due, e.g. to unexpected changes in unemployment, or persistent aggregate supply shocks due, e.g., to increases in productivity (see Blanchard and Quah, 1989). However, it is important to keep these different sources of "world output-driven demand shocks" in mind when it comes to explaining mineral commodity production.

Supply shocks

I define "supply shocks" 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 primary production of the respective commodity in the long-run. In contrast, price changes driven by "other demand shocks" exhibit only a transitory effect on world primary production. They hence affect only capacity utilisation of the extractive sector but not long term investment decisions. This is plausible, given the fact that expanding extraction and first-stage processing capacities exhibits high upfront costs and takes many years (Radetzki 2008; Wellmer 1992). This makes it likely that "other demand shocks" affect world primary production only in the short-term.

Other demand shocks

Other demand shocks encompass all innovations to the respective real mineral commodity price that are driven neither by the "world output-driven demand shocks" nor the "supply shocks". It hence captures all shocks that are uncorrelated to these two latter shocks. These in turn mainly capture changes in the demand for inventories due to government stocking programs, producer market power, and shifts in expectations of the downstream processing industry about the future supply and demand balance (see on the last point Kilian 2009; Kilian / Murphy 2012).

Overall, this methodology allows me to identify the effects of demand and supply shocks on mineral commodity prices and to estimate long-run price trends. Theoretical models make different predictions on the long term trends and the type of shocks that drive fluctuations in prices. The seminal Hotelling (1931) model predicts an increasing trend in prices, while it makes no statement on price fluctuations. Extensions of the Hotelling (1931) model such as those by Arrow and Chang (1982), Fourgeaud et al. (1982), and Cairns and Lasserre (1986) introduce the exploration of deposits which causes sudden price changes. Following this literature, I would expect "supply shocks" to mainly drive price fluctuations. These models predict different short term price trends, but mainly point to increasing trends in the long term.

Competitive storage models (Gustafson 1958a, b; Wright / Williams 1982) usually assume supply shocks as the source of uncertainty.[2] Storage smoothes these shocks intertemporally and explains the empirically observed autocorrelation in prices. Commodity storage models do not make a prediction concerning the trend. Based on this literature I would expect supply shocks to drive fluctuations in prices. Alquist and Kilian (2010) and Kilian and Murphy (2012) extent the storage model in a way that storage in the presence of expected supply shortfalls explains price fluctuations. These shocks would show up in the "other demand shocks" in our model. Finally, some scholars have explicitely modelled demand shocks. Dvir and Rogoff (2010) introduce persistent demand shocks to a competitive storage model. In this model storage amplifies rather than smoothes these shocks if supply is restricted. Mitraille and Thille (2009) endogenize production and therefore regard demand shocks as the source of uncertainty in a competitive storage model. Bodenstein and Guerrieri (2011) introduce several types of demand shocks in a two-country DSGE model. Overall, these models seem to suggest that demand shocks drive price fluctuations.

5 Empirical results

I employ ordinary least squares to consistently estimate the reduced-form coefficients of the VAR models of each of the four 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. For each mineral commodity, I first 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.

2 However, these models ultimately leave the source of shocks open, since shocks to demand and supply are "isomorphic" in the model setup (Dvir / Rogoff, 2010, 10).

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. The two figures are related as a positive structural shock drives upwards the curve of the cumulative effect of the shocks in the historical decomposition.

5.1 Copper market

My results show 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. 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).

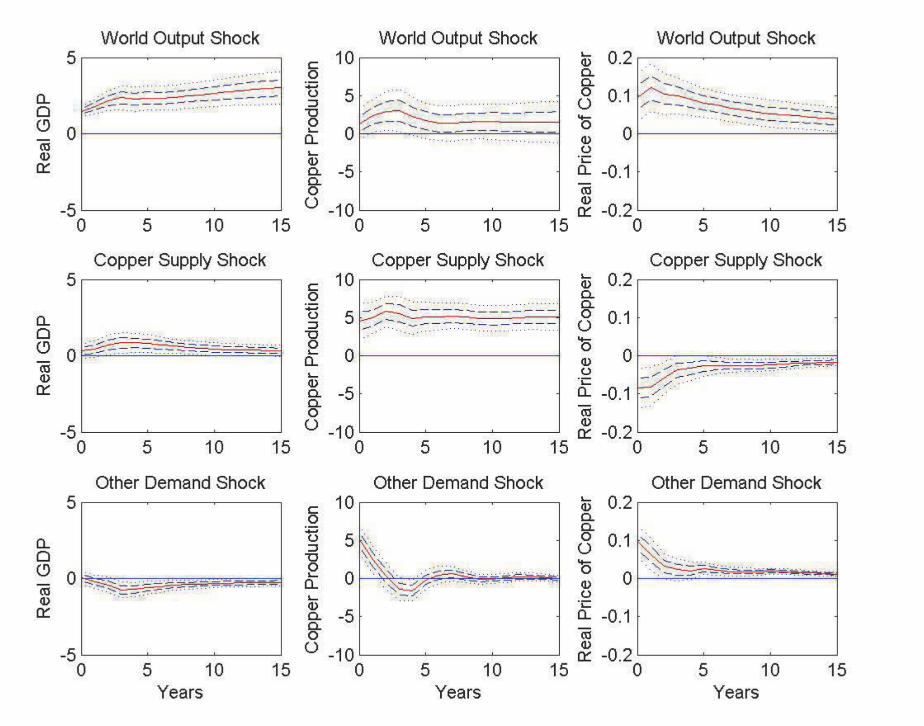
The impulse response functions in Figure 2 show that a positive "world output-driven demand shock" exhibits a strong, positive, and persistent effect on world GDP. It causes a positive significant increase in copper production that lasts for about three years. Finally, it triggers a major increase in the real price of copper for a maximum of 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 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.

In the late 1840s the price of copper was low owing to the British railway crisis from 1847 to 1848 (see Kindleberger / 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 / 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 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 American Civil War from 1861 to 1865, and the Overend-Gurney Crisis in 1866 and their respective economic aftermaths (see Kindleberger / Aliber 2011). At the same time, there was some

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



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.

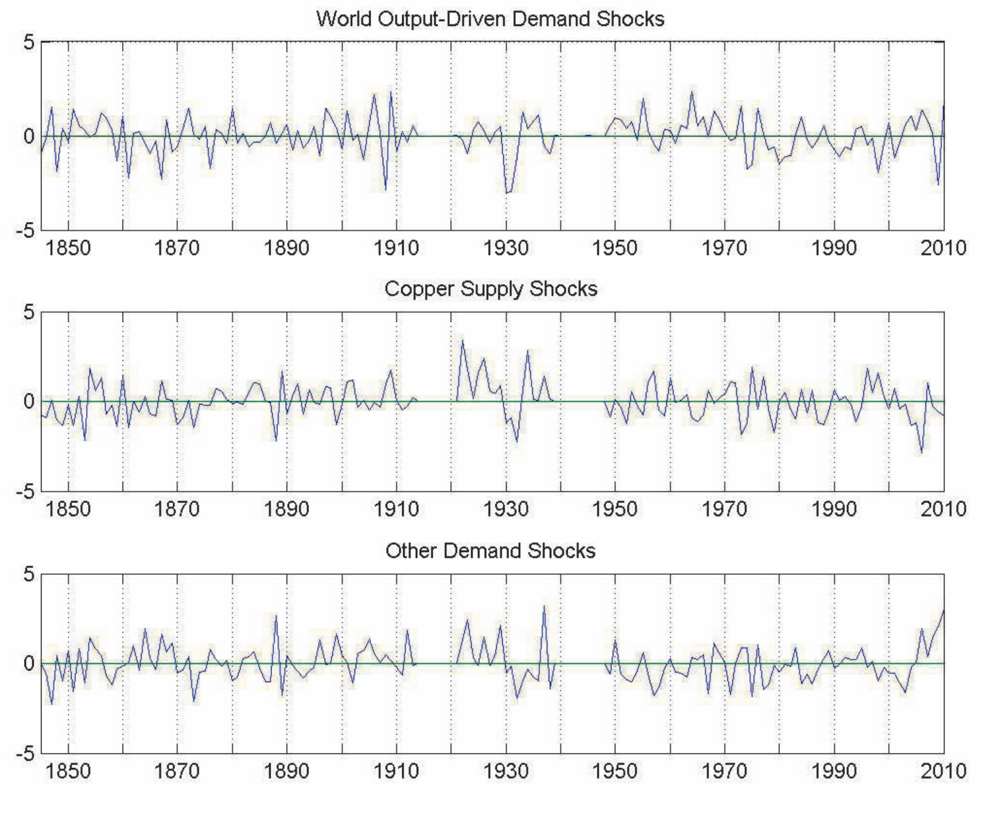
downward pressure caused by positive "supply shocks" due to the opening of new mines in Arizona and Michigan - despite the problems posed by the Civil War - and a substantial increase in production in Chile and elsewhere in the world, especially in the late 1860s (Richter 1927).

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 / Aliber 2011). Second, major, positive "supply shocks" drove prices down. Between 1875 and 1885, annual U.S. copper production rose by more than 500 per-cent. The Anaconda mine in Montana "proved fabulously rich and enormously productive" (Richter 1927, 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, 257). This explains the negative "supply shock" at that time.

In response, the new Secrétan copper syndicate, which controlled up to eighty percent of world production, became active from 1887 to 1889 (Richter 1927; Herfindahl 1959),

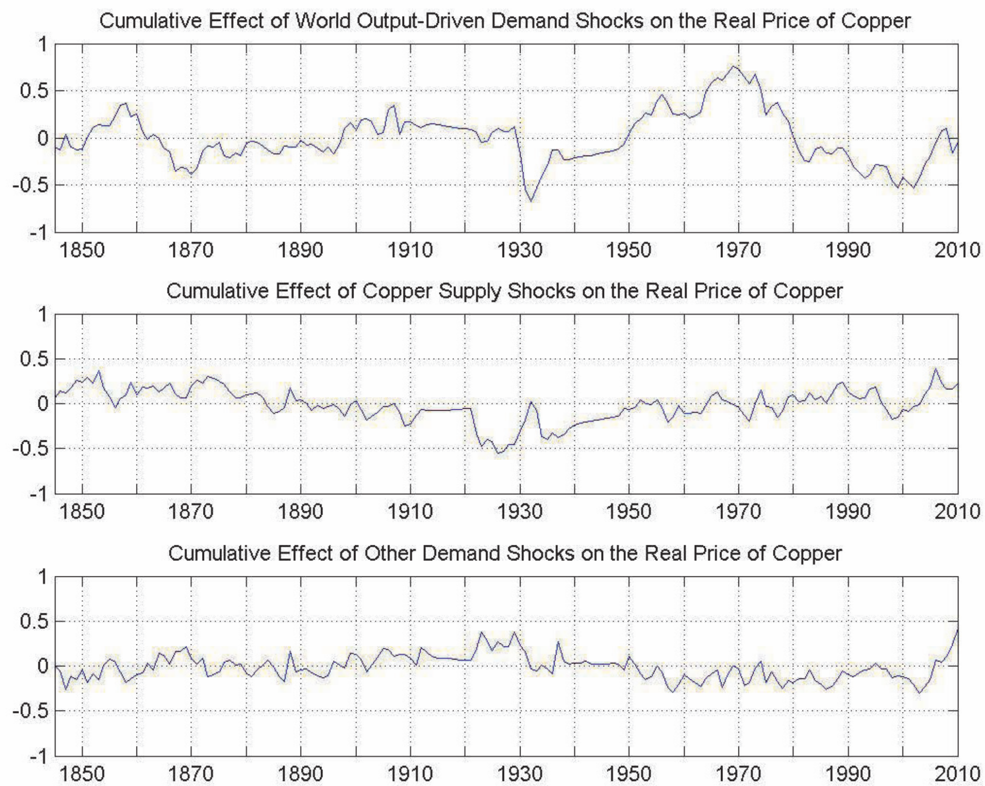
Figure 3: Historical evolution of structural shocks for copper



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 b ank, 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, 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 a financial crisis in the U.S as described by Kindleberger / Aliber (2011) (see also data provided by Crafts et al. 1989; NBER 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 and number of other firms tried to stabilize the price of copper by withholding stocks from the markets and restricting output (Herfindahl 1959, 81). This is also revealed 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, 83-91). These manipulations played a major part in the fluctuations in the price of copper, 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, 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, 278-81).

Figure 4: Historical decomposition of the real price of 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.

The price of copper stayed relatively flat during the 1920s, with a small peak in 1 929. 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 Association3. In 1917 world refined production totalled 1.4 million metric t ons. 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 cease. 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 (Herfindahl 1959, 93-4) in the early 1920s and later by the Copper Exporters Inc. (Herfindahl 1959, 100-6).

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, 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, 105). In 1935 the International Copper Cartel emerged and succeeded in driving up the price of copper in the late 1930s (Herfindahl 1959, 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 prices. 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. Volun-tary 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 produc-tion in 1975 aggravated the negative "supply shocks" (see Sachs 1999; Mardones et al. 1985). 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, 205), as is evident from the strong accumulative effects of "supply shocks" and "other demand shocks". On the other hand, the recessions 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

3 Please note that I have not included the three years after the First and Second World Wars in my regressions.

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 for 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 proveded 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 restriction output and by stocking. The evidence points to inventory changes by producer cartels, governments, and in the last years of investors as a key driver of "other demand shocks".

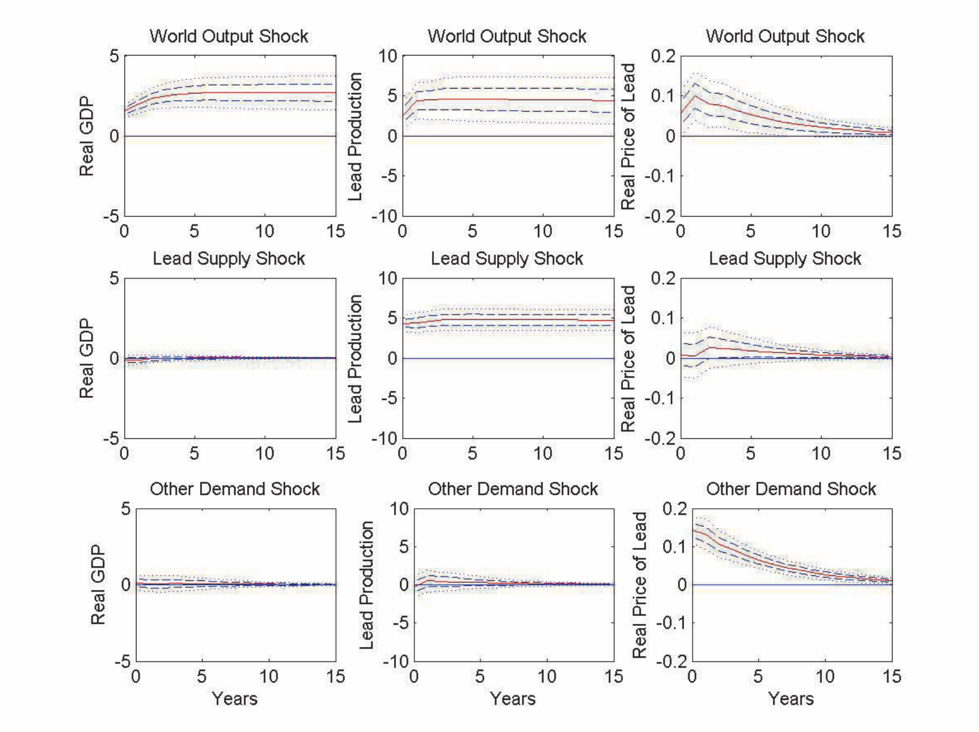
5.2 Lead market

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 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 country (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 function 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.

A positive unexpected shock to the supply of lead does not cause a significant change in world GDP, but does have a strong, significant, and persistent effect on world production of lead. It has a slightly positive, but insignificant effect on the real price of lead. This result is in line with my finding for zinc, where the effect of "supply shock" on the price is also insignificant. In the copper and tin markets, on the other hand, positive "supply shocks" have a strong and significant effect on price. I ascribe the difference to market structures. Copper and tin production are horizontally more concentrated than that of zinc and lead (BGR 2007; Rudolf Wolff & Co Lt. 1987). In addition, copper and tin tend to be mined in developing countries, while lead and zinc are mined mainly in industrialized countries that also use lead and zinc as manufacturing

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



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.

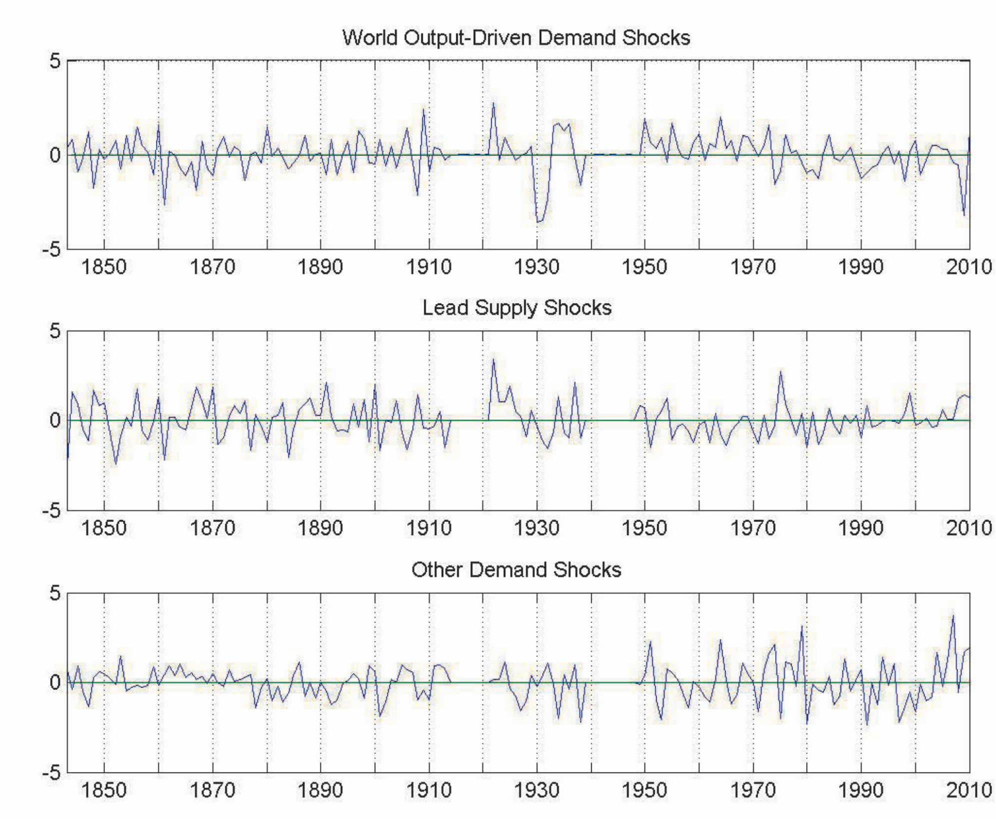
inputs (Rudolf Wolff & Co Lt. 1987; Schmitz 1979; BGR 2007). As a consequence, shocks to supply, in the form of coordinated production decreases by a cartell, for example, have an impact on copper and tin prices, but do not affect the zinc and lead markets.

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.

Lead price was driven mainly by world output-led demand shocks and "other demand shocks" in the period considered. Prices rose in the early 1850s and remained at this level for the next decade. Overall, prices remained relatively stable until the 1880s, compared to the other three mineral commodities examined. McCune-Lindsay (1893) comes to the conclusion that the price of lead was affected far less by a "twist of fate" (McCune-Lindsay 1893, 150). He also adds that it is impossible to find data on stocks that explain movements in the price of lead.

Unfortunately, not much is known about the lead market in the 19th century. "Other demand shocks" in the mid 1860s may have been due to the consider uncertainty in the market about the Austro-Prussian War that probably affected trade in zinc from its main production sites in Silesia. Moreover, according to (Gibson-Jarvie 1983) the zinc industry has always been prone to producer cartels in the main producing country Germany, where "the cartel 'rationale' generally was both established and indeed encouraged...." (Gibson-Jarvie 1983, 73). Throughout the last decade of the 19th century there were "repeated rumours in circulation as to a potential zinc cartel (...) sufficiently strong as to have an unsettling effect on prices" (Gibson-Jarvie 1983, 73). However, as producers were unable to agree on or sustain production limits, these rumours faded again (Gibson-Jarvie 1983, 73). In its account of copper prices in 1900 and 1901, (Metallgesellschaft 1904) mentions that the Lead Trust, a large cartel in the U.S., limited its production, and stocks increased so sharply that prices rose for a time (Metallgesellschaft 1904). Overall, these ups and downs in cartel action may explain the "other demand shocks" that drove up prices in the mid 1890s, then vanished and had a strong positive impact on prices again in the mid 1910s.

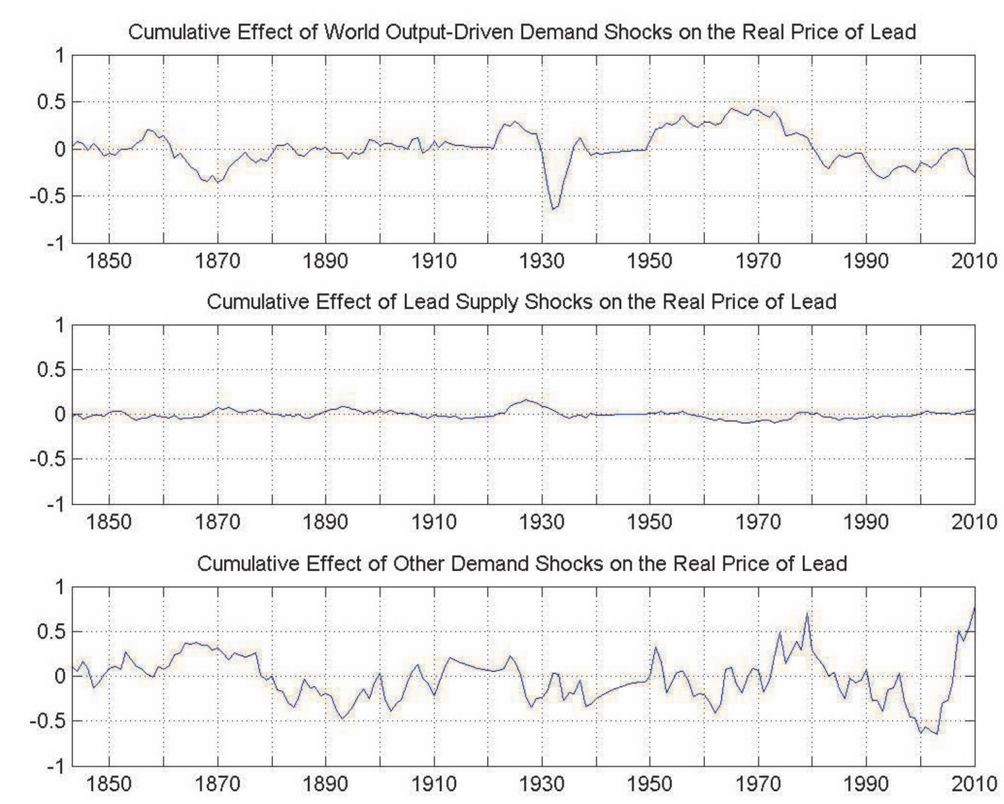
Figure 6: Historical evolution of structural shocks for lead



In 1909 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 used stocks to withhold lead from the market (Gibson-Jarvie 1983). The "other demand shocks" show that,as a historical account claims, the Association was relatively successful in driving up prices from 1910 to 1913 (Gibson-Jarvie 1983).

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

Figure 7: Historical decomposition of the real price of lead



1983, 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 (Gibson-Jarvie 1983; Hughes 1938).

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 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, 684). In 1951 the U.S. government set a price ceiling (see Bishop and den Hartog 1954, 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 wordwide 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 as the "other demand shocks" that drove the price up rather than supply shortages. There were also 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 these 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 to the phasing out of lead from many domesticappliances, 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 encompasses shocks to the use of lead due to environmental regulation in the 1970s and 1980s.

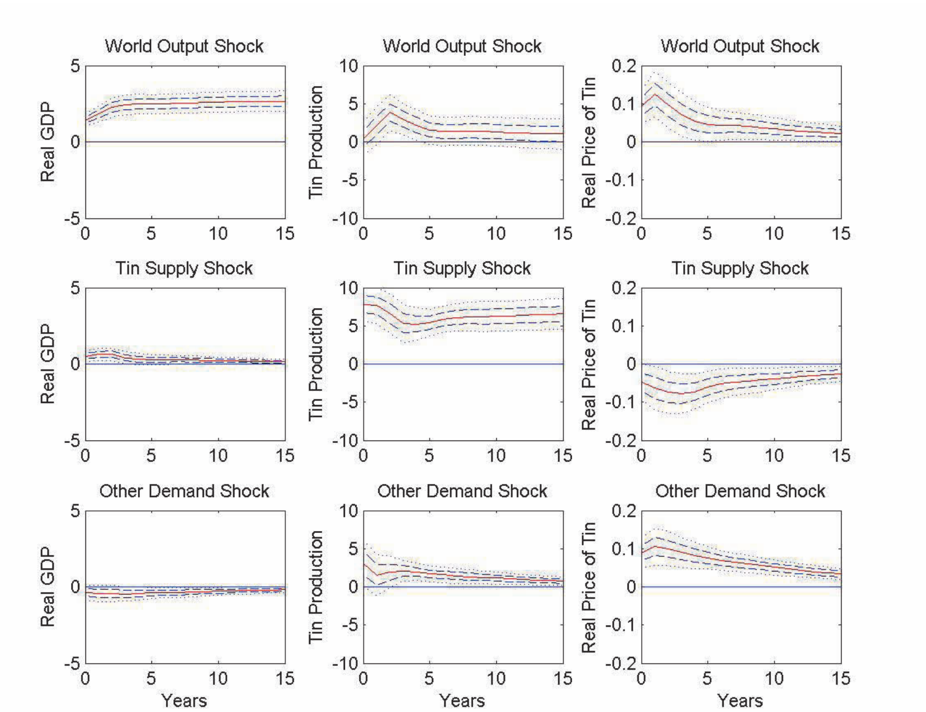
5.3 Tin market

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 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, 1)

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, 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.

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

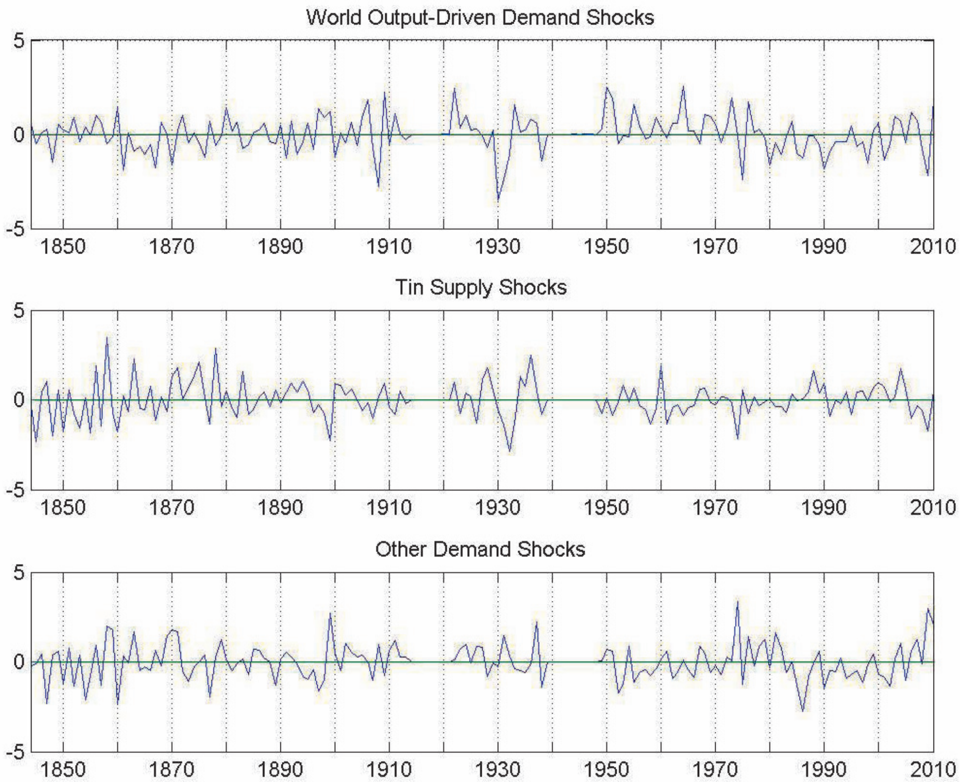


Notes: Point estimates with one- and two-standard error bands based on Model (1). I use accumulated impulse response functions for the shocks on world mineral commodity production and world GDP to trace out the effects on the levels of these variables.

Finally, I find that positive “other demand shocks” have no statistically significant impact on world GDP but exhibit a positiv rather small effect on tin production which turns statistically significant about three years after the shock hit. Due to my long-run restrictions, the effects levels off over time. An unexpected increase in “other demand” leads to a strong and positive increase of the real price of tin that keeps on being statistically significant for more than fifteen years.

According to my findings, these fluctuations are driven mainly 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 / 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

Figure 9: Historical evolution of structural shocks for tin

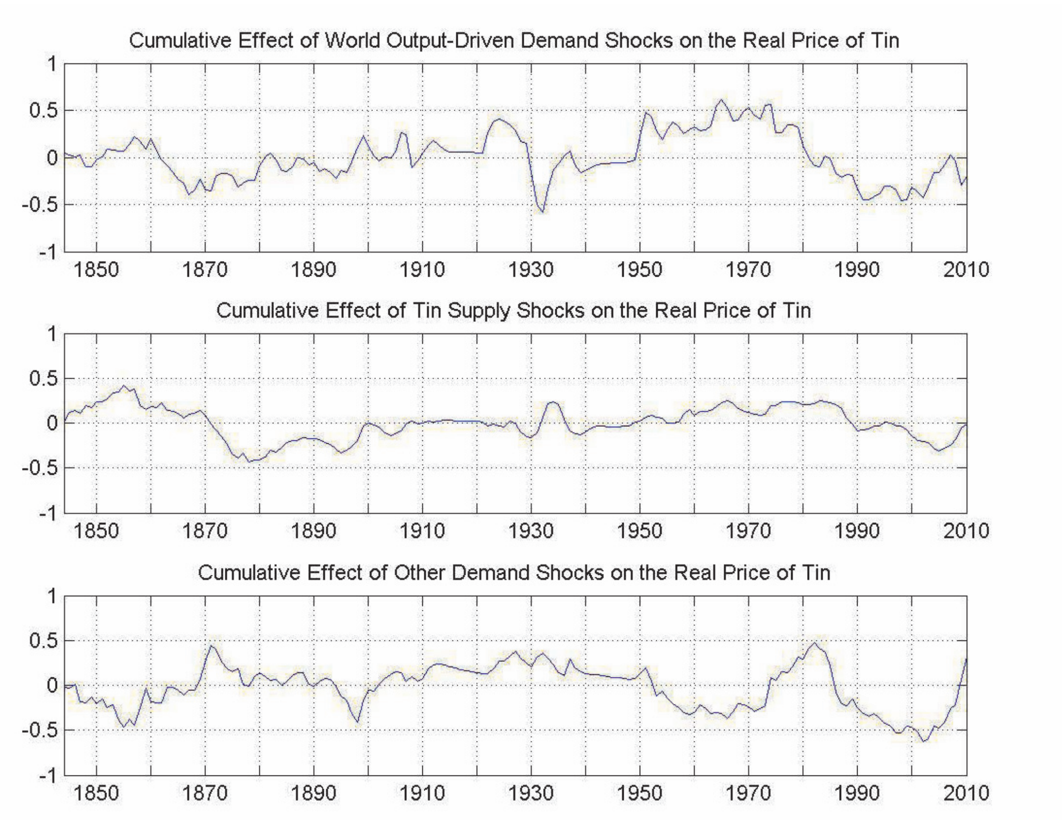


Neumann 1904, 251-2). "Other demand shocks" also exerted downward pressure on the price, but their sources are not identifiable from the literature.

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. 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 / 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). Britain intervened and took control of important parts of the Malayan peninsual 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 stockholding 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 significantincrease 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".

Figure 10: Historical decomposition of the real price of tin



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; NBER 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; NBER 2010).

Price fluctuations in the inter-war period were influenced mainly by the economic recovery after the First World War, the effects of the Great Depression and the attempts to form cartels. In 1921 the governments of the Federated Malay States and the Dutch East Indies establishd the Bandoeng Pool and agreed to stabilise the price of tin by jointly managing inventories (Thoburn 1994). The Bandoeng Pool controlled more than 50 percent of world production at the time (Thoburn 1994, 77). From 1921 to 1923 it withheld some fifteen percent of world tin production from the market and sold it gradually when prices rose mid 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, 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 unsuccesssful, 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 programme. 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 with 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 / Schink 1976). From an examination of "other demand shocks" it seems that the downward pressure of subsequent releases from the U.S. stockpiling programme 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 levelled-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 been due not only by restocking at producers and consumers, but also, according to industry obsevers, to stockpiling by investment funds as attribute (U.S. Geological Survey 2011b).

Overall, my results provide evidence that fluctuations in the tin price 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 build-up and collapse of the International Tin Agreement which influenced the price strongly over several decades.

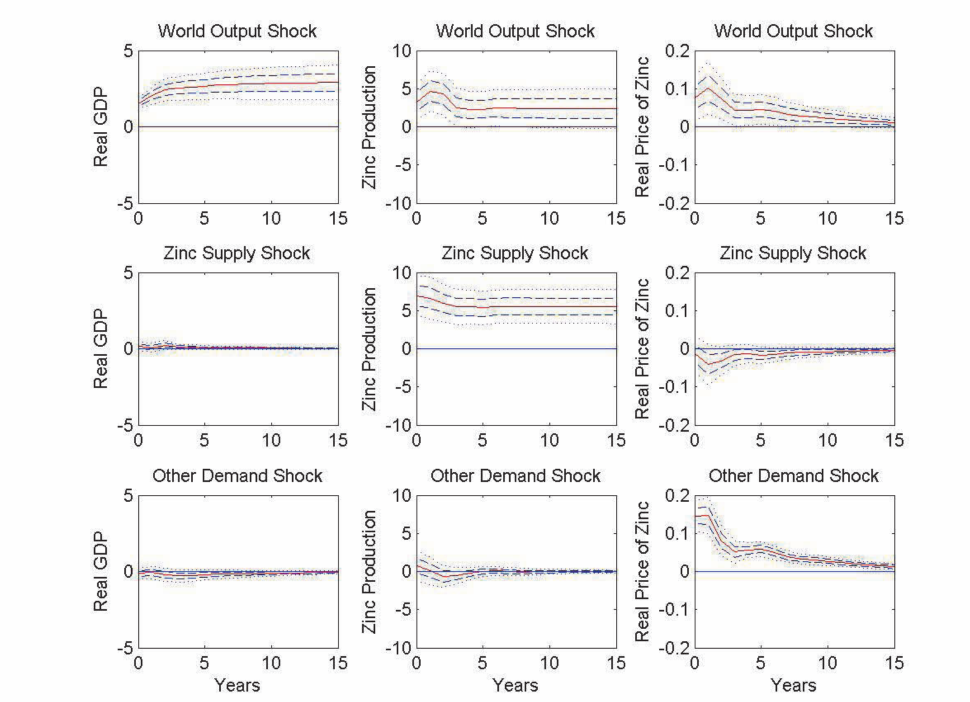
5.4 Zinc market

My results show that "world output-driven demand shocks" and "other demand shocks" are the main drivers of fluctuations in the real price of z inc. As it is the case for lead, zinc is basically produced in industrialised 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 behaviour of the zinc market is very similar to that of the lead. An unexpected rise in demand due to an increase in world output is causing 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.

An unexpected increase in zinc supply does not have an effect on world GDP, but has a string positive impact on zinc production, as is to be expected 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

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



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.

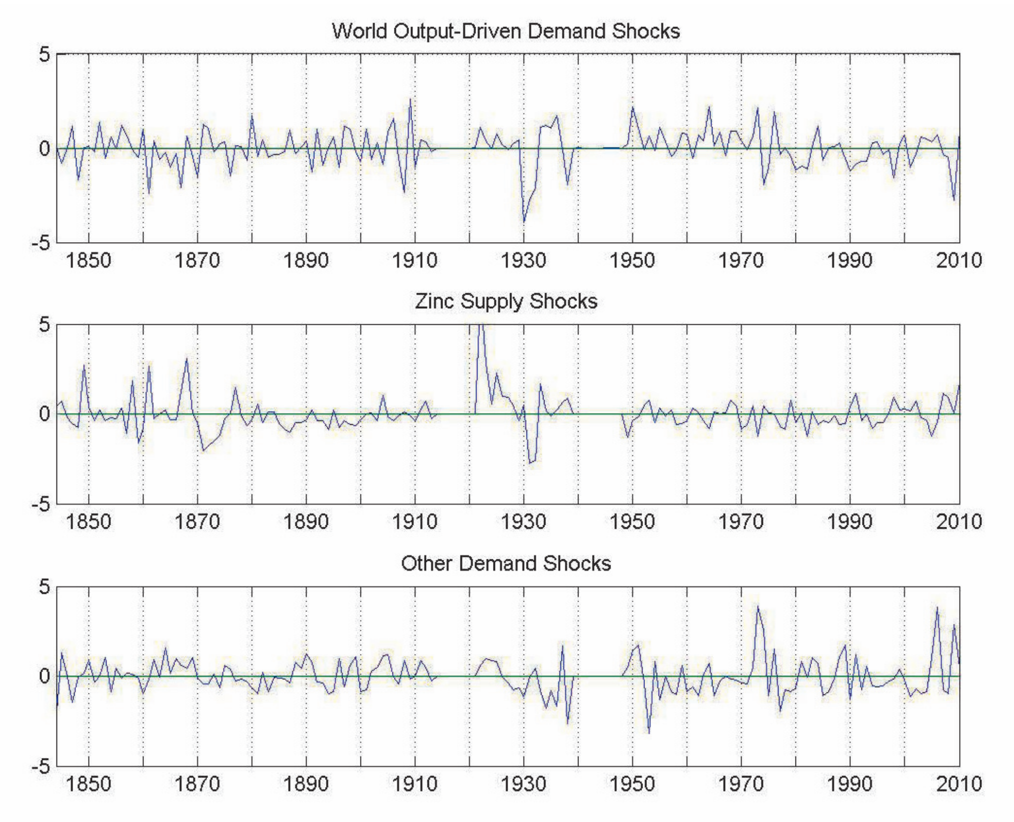
Wolff & Co Lt. 1987; Schmitz 1979; BGR 2007). As a consequence, shocks to supply in the form of coordinated production decreases by a cartell, for example, have an impact on copper and tin prices, without affecting the zinc and lead markets.

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. Prices rose sharply in the 1850s and peaked in 1857, driven mainly by the accumulative effects of "positive output-driven demand shocks" as the world economy boomed in the 1850s (see Kindleberger / 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 / 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. 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 stocks. I leave it to future research to delve deaper into the history of the zinc market around that time.

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 / Walters 1968). These attempts failed, since local production decreases were offset by production elsewhere (Jolly 1997; Cocks / Walters, 1968). As a result, negative "other demand shocks" in combination with "world output-driven demand shocks" caused by the Long Depression exerted downward pressure on prices, which reached their lowest level in the mid-1880s.

Figure 12: Historical evolution of structural shocks for zinc



As a reaction to the low prices in the 1880s, major European producers joined the "first significant international zinc cartel" (Jolly 1997, 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 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.

Prices 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 smeltering plants 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 / Walters 1968, 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).

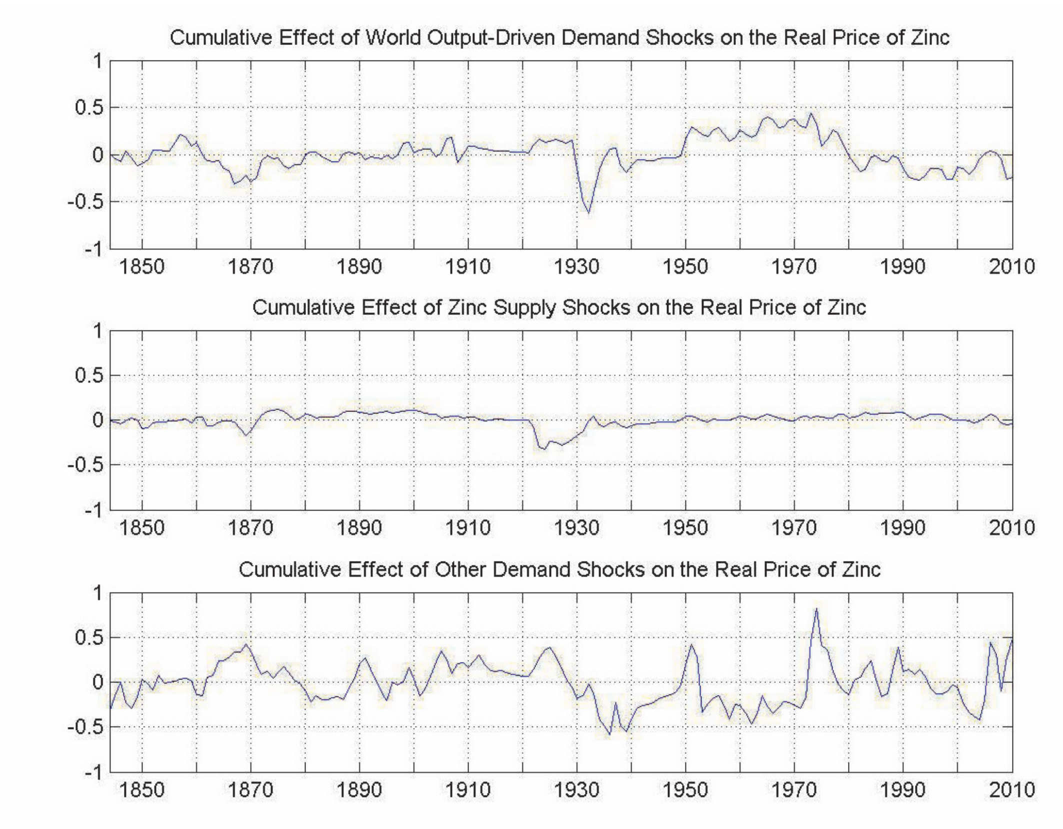
In the inter-war period, prices began by falling, then rose to a peak in the mid-1920s, slumped sharply during the Great Depression and did not recover from this low level until the end of the Second World War. My analysis shows the peak in the mid-1920s to be the result of positive "world output-driven 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 technique of smelting which made the zinc production from complex sulphide ores possible (Gupta 1982). These new techniques increased production especially in non-European areas such as Canada, Australia, Mexico, Rhodesia, and Indochina (Gupta 1982). As a result the production of flotation concentrate in the U.S. for example increase from 34,000 tons in 1921 to 500,000 tons in 1928 (Jolly 1997, 39).

The new competition from outside Europe triggered the formation of the European zinc cartel in 1928 but which was dissolved in 1929 due to disparate interests of its members (Jolly 1997; Gupta 1982). The Great Depression caused a major negative "world output-driven demand shock" in 1930 and send prices down. As a reaction, the European zinc cartel was revived and imposed a 45 percent cutback of production in 1931 which was raised to 55 percent in the following year (Jolly 1997). This explains the negative "supply shocks" during these two years. However, the cartel dissolved in 1934 as some participants cheated on their production and sales. Problems with the treatment of stocks, which started to be released on the market as "other demand shocks" show, were not solved (Jolly 1997; Gupta 1982). Several attempts to renew the cartel failed until a cartel called the International Sheet Zinc Cartel was founded at the end of the 1930s. It had a short impact on the market as the "other demand shocks" suggest but was dissolved by the start of World War II (Jolly 1997).

The high price level from the end World War II until the beginning of the 1970s was mainly driven by upwards pressure due to strong "world output-driven demand shocks" fueled by post-war reconstruction and the following industrial expansion in South-Korea and Japan. After World War II the U.S. enacted the Strategic and Critical Minerals Stock Piling Act which led to heavy stockpiling, visible in the sharp rise of accumulated "other demand shocks" and driving up prices enormously (Gupta 1982, 32). The following years were characterized by price controls and sales and purchases into the government stockpile in the U.S.. This economic policy strongly influenced the price in the rest of the world and had a rather destabilizing effect (Gupta 1982, 32). It is also visible ithe "other demand shocks". Furthermore, a new informal cartel was founded in 1964, known as the "Zinc Club" (Jolly 1997, 117). Its members, mainly European, Canadian, and Australian zinc companies aimed at supporting the newly introduced European Producer Price and to restrain the influence of the London Metal Exchange (Jolly 1997). They used inventories as a tool to set the European Producer Price (Jolly 1997).

At the beginning of the 1970s the zinc price increased dramatically. My analysis shows that

Figure 13: Historical decomposition of the real price of zinc



this was mainly driven by "other demand shocks". The U.S. government imposed a stabilization program in 1971 which fixed prices at a low level (Jolly 1997). After lifting the fixed price in 1973, both the U.S. producers and the "Zinc Club" increased their prices sharply by more than 225 percent (Gupta 1982, 30). As producers withhold stocks, visible in the strong accumulated response of the "other demand shocks", the price of the London Metal Exchange also increased drastically. In 1974 the recession had a strong negative shock on the price and producers were not able to support prices anymore such that prices dropped again (Gupta 1982). The governments of the U.S., Japan, and France helped zinc companies to reduce inventories in these times of a low zinc price by increasing government stocks in 1975 and 1976 (Gupta 1982). After investigations of the U.S. department of Justice, the informal "Zinc Club" collapsed in 1976 (Jolly 1997).

In the 1980s the zinc price reached peaks in the middle of the 1980s and at the end of the 1980s. Both are explainable by a combination of positive "world output-driven demand shocks" due to economic expansions of the world economcy (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 the zinc price over 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 Asian Crisis later on. The price increase at the beginning of the 2000s was fueled by positive “world output-driven demand shocks” until the Great Recession starting in late 2007 caused strongest negative “world output-driven demand shocks”. However, strong positive “other demand shocks” partly compensated for these negative shocks. They reflect a strong change in warehouse inventories of the London Metal Exchange and the Shanghai Futures Exchange, which have increased eightfold and sixfold in the period from 2007 to 2010 (International Lead and Zinc Study Group 2011). Interestingly data on inventories at consumers and producers have not increased over the time period (International Lead and Zinc Study Group 2011), which points to the role of institutional investors in buying 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 in recent time as an interpretation of the “other demand shock”.

5.5 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 trendless 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.

Table 1: Estimated coefficients of the linear trends

	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

6 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 for my baseline specification.

In order to check the robustness of the results over that of an alternative identification, I use Kilian’s identification scheme, which is based on short-run restrictions. I postulate a vertical short-run supply shape 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 also robust regarding alternative price data. Table 25 illustrates the empirical results obtained from using the producer price index instead of the consumer price index for disinflation.

Employing New York prices instead of London based prices (see Table 26) 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 subperiods. 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 24).

7 The case of crude oil

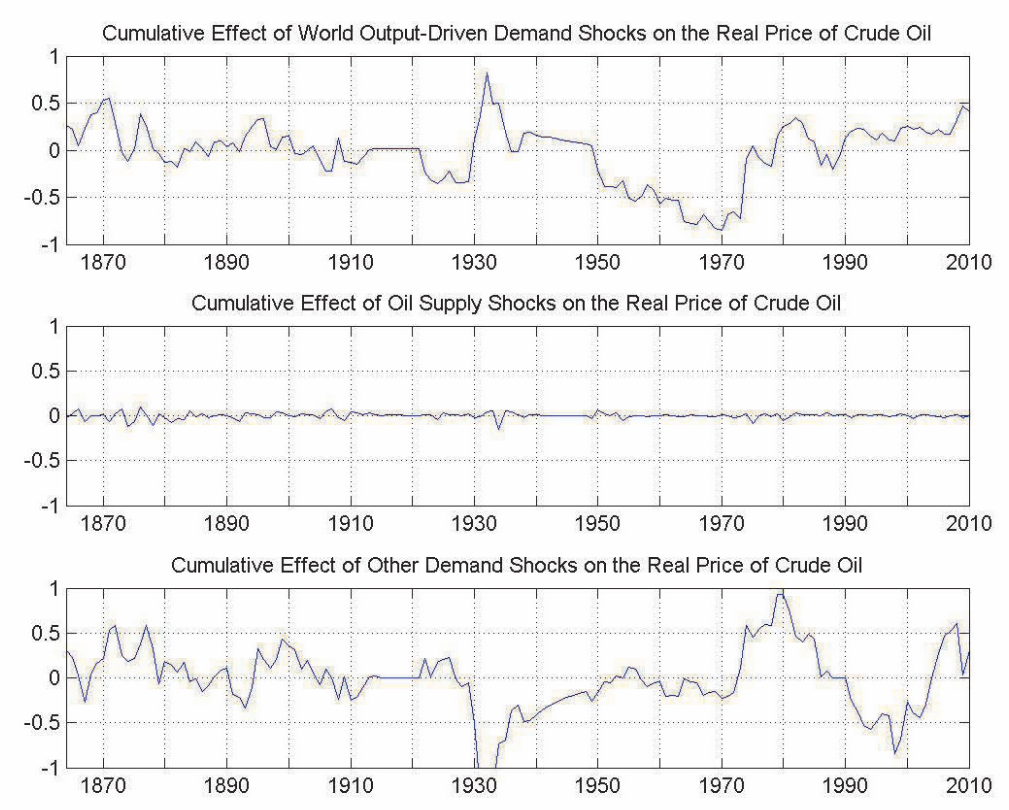
While the empirical results are quite robust for the four mineral commodities examined above, the results for the crude oil market are less compelling due to structural breaks in the time series. As a comparison, I present the empirical results in the following. The evolution of the variables is presented 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 Appenxid 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 behaviour is the still unsettled issue of causality in the relationship between the oil price and economic growth (see, e.g., Ozturk (2010) for an overview). 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.

The historical decomposition in Figure 14 reveals again the problem with 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.

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



The results for crude oil are not robust with respect to different subperiods due to the familiar structural changes in the oil market (see Kilian / Vigfusson 2011; Dvir / Rogoff 2010; Hamilton 2011). Results for the subperiods from 1900 to 2010 and from 1925 to 2010, which are presented in Table 24 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.

8 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 from 1840 to 2010. 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 hereby 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 controling for changes in inventories or the resource intensity of the economy would shed further light on the sources of these shocks.

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Appendices

Appendix 1 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 terms, notably 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

$$A z_t = \Gamma_1 z_{t-1} + ... + \Gamma_p z_{t-p} + \Pi D_t + \varepsilon_t \ . \tag{2}$$

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

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

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 (2008) 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 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 the Federal Institute for Geosciences and Natural Resources)
	1929-1959	mt	Schmitz 1979, pp. 213-25	Refined production; according to the Federal Institute for Geosciences and Natural Resource the data includes both primary and secondary sources. This is also the case 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 - including production on toll in the reporting country regardless of the type of source material, i.e. whether 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.
Tin	1821-1883	mt	Neumann 1904, p. 251-3	
	1884-2010	mt	BGR, 2012	Primary tin production (smelter)
Zinc	1850-1879	mt	Schmitz 1979, p. 160-6	Mine production
	1880-1888	mt	Metallgesellschaft 1898, 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 including production on toll in the reporting country regardless of the type of source material, i.e. whether ores, concentrates, residues, slag, or scrap. Remelted zinc and zinc dust are excluded.
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	1771-1976	£/mt	Schmitz 1979, p. 268-72	1771-1779: Cornish copper standard; 1780-1879: 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; 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-$/mt	BGR, 2011	Grade A, cash, in LME warehouse
	New York	1850-1976	US-$/mt	Schmitz 1979, p. 268-72	1850-1899: Lake copper (fire-refined) New York; 1900-1976: electrolytic wirebars; Sep 1967-Apr 1968: US copper producer strike, so 1967 is the average of Jan-June and 1968 is the average of May-Dec.
	New York	1977-2010	US-$/mt	U.S. Geological Survey 2011a	U.S. Producer Price
Lead	London	1771-1976	£/mt	Schmitz 1979, p. 226-37	1771-1886: English pig lead, mostly prices in provincial markets pre-1850, then mainly London prices; 1887-1945: good soft pig lead; 1946-1976: refined pig, min. 99.97% metal content; 1914: average Jan-July and Nov-Dec only; 1940-Sept 1952: fixed selling price, Ministry of Supply
	London	1977-2010	US-$/mt	BGR, 2011	min. 99.97 %, LME, cash, in LME Lagerhaus
	New York	1812-1976	US-$/mt	Schmitz 1979, p. 274-78	1812-1879: pig lead, New York; 1880-1976: common grade lead, min. 99.73%
	New York	1977-2010	US-$/mt	U.S. Geological Survey 2011a	Domestic refined lead
Tin	London	1750-1976	£/mt	Schmitz 1979, p. 240-1	1750-1837: common refined tin, Cornwall; 1838-1872: standard tin; 1873-1976: standard tin, min. 99.75% cont.; 1914: Average price of Jan-July and Oct-Dec only; 1942-1949: controlled price, Ministry of Supply
	London	1977-1978	US-$/mt	U.S. Bureau of Mines 1980, p. 915	
	London	1979-2010	US-$/mt	BGR, 2011	Min. 99.85%, LME, cash, noon of tin in blocks and pigs from the U.K.
	New York	1851-1855	US-$/mt		Filled with linear trend

	New York	1856-1962	US-$/mt	Secretary of the Treasury 1864, p. 46-8	Computed from quantities and values of imports of tin in blocks and pigs
	New York	1863	US-$/mt	House of Commons 1866, p. 358	Computed from quantities and values of imports of tin in blocks and pigs
	New York	1864-1865	US-$/mt	House of Commons 1868, p. 378	Computed from quantities and values of imports of tin in blocks and pigs
	New York	1866-1869	US-$/mt		Filled with linear trend
	New York	1977-2011	US-$/mt	U.S. Geological Survey 2011a	Domestic refined tin; 2004: New York composite price.
Zinc	London	1823-1976	£/mt	Schmitz 1979, p. 299-303	1823-1951: Ordinary brands zinc, London market; 1940-1944: controlled price, U.K Ministry of Supply; 1952-1976: virgin zinc min. 98%, London market
	London	1977-1978	US-$/mt	U.S. Bureau of Mines 1980, p. 981	Prime Western grade, London
	London	1979-2010	US-$/mt	BGR, 2011	Special high grade, min. 99.995%, cash, LME warehouse
	New York	1853	US-$/mt	Schmitz 1979, p. 300-3	Prime Western Spelter, New York
	New York	1859, 1860	US-$/mt	House of Commons 1862	Import price of zinc in blocks and sheets
	New York	1863	US-$/mt	House of Commons 1866	Import price of zinc in blocks and sheets
	New York	1864-1865	US-$/mt	House of Commons 1868	Import price of zinc in blocks and sheets
	New York	1872-1874	US-$/mt	U.S. Bureau of Mines 1883	Import price of zinc in blocks or pigs
	New York	1875-1976	US-$/t	Schmitz 1979, p. 300-3	1875-1899: Prime Western Spelter, New York; 1900-1976: Prime Western Spelter, Saint Louis
	New York	1977-2010	US-$/mt	BGR, 2011	1977-2001: High-grade; 2002-2010: Special high grade
Crude Oil	US/UK	1861-2010	US-$/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
British £- US-$	1791-2010	US-$ per £	Officer 2011

Table 4: Data sources for the exchange rates.

Index	Country	Time	Unit	Source	Notes
PPI	U.K.	1840-1913	2005=100	Mitchell 1988, p. 722-4	
	U.K.	1914-1959	2005=100	Mitchell 1988, p. 725-7	
	U.K.	1960-2010	2005=100	World Bank 2012	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.	1800-2010	Jan 1974=100	U.K. Office of Statistics 2011	Composite Price Index
	U.S.	1774-2008	1982-1984=100	Officer and Williamson 2011	

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 Figures

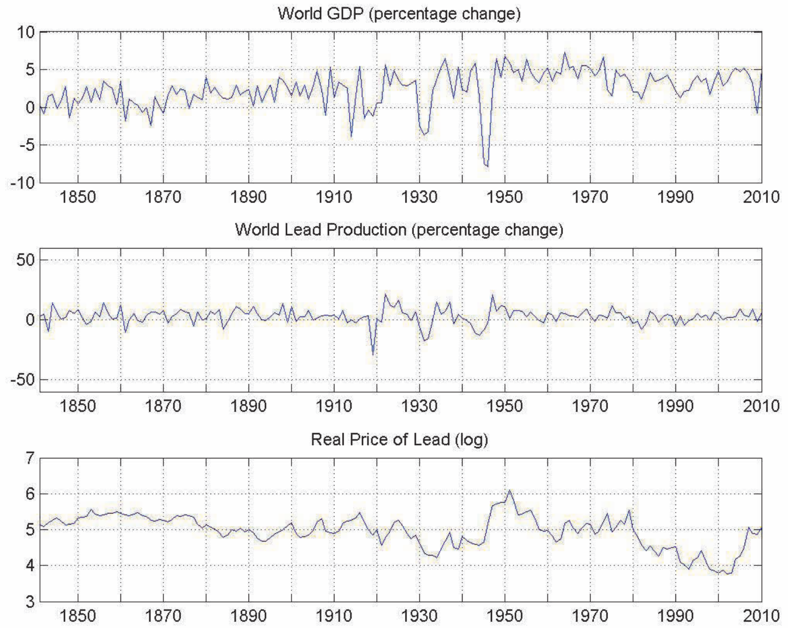


Figure 15: Historical evolution of world GDP, world lead production, and the real price of lead from 1841 to 2010.

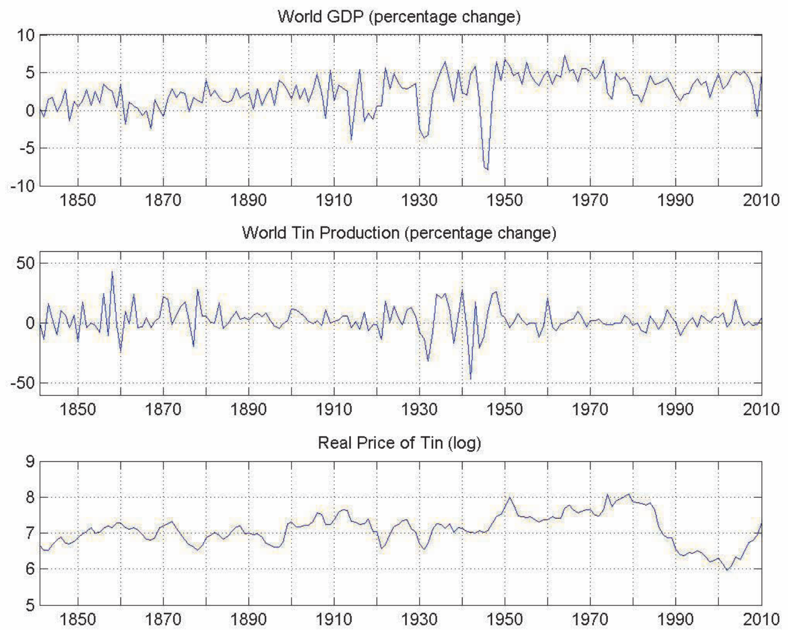


Figure 16: Historical evolution of world GDP, world tin production, and the real price of tin from 1841 to 2010.

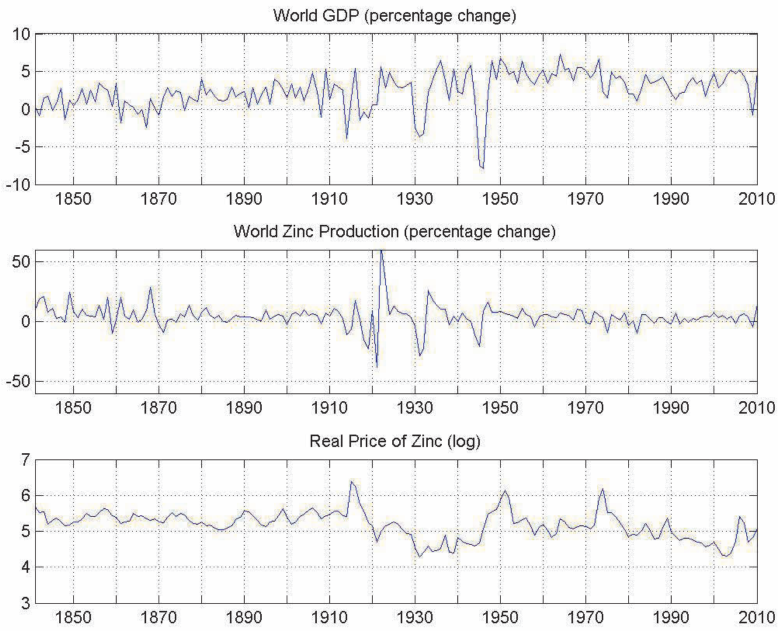


Figure 17: Historical evolution of world GDP, world zinc production, and the real price of zinc from 1841 to 2010.

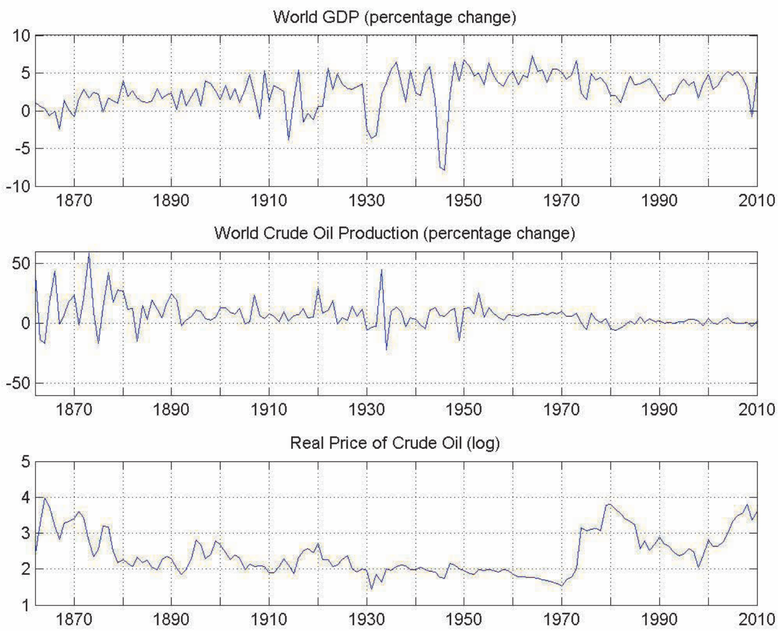


Figure 18: Historical evolution of world GDP, world crude oil production, and the real price of oil from 1862 to 2010.

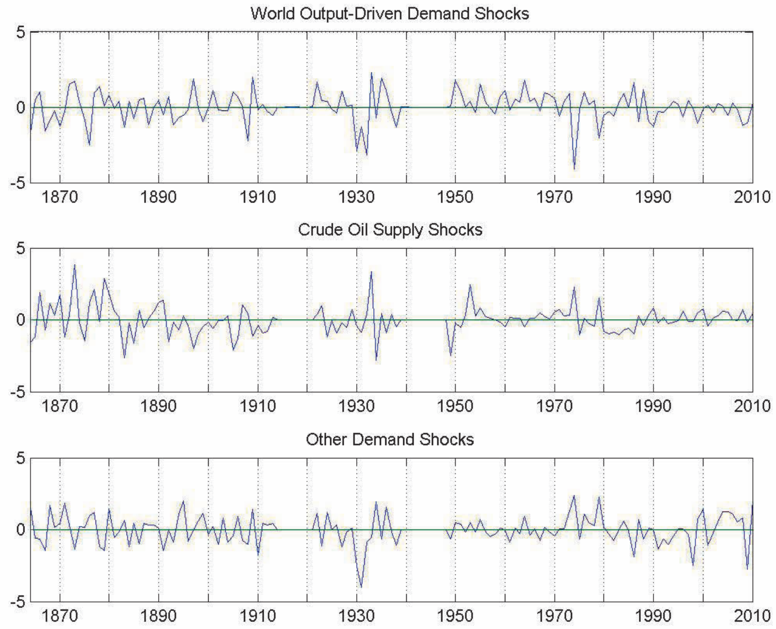
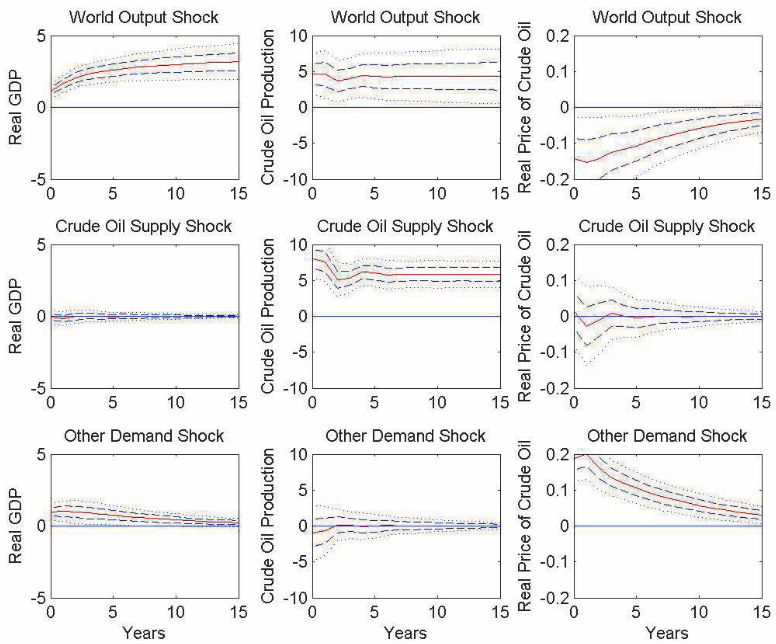


Figure 19: Historical evolution of the structural shocks for crude oil.



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.

Appendix 4 Regression results

Indep. variable	Coefficient	t-statistic	t-probability
Dependent variable: World GDP (percentage share)			
World GDP lag1	0.375	3.964	0.000
World GDP lag2	0.353	3.281	0.001
World GDP lag3	0.149	1.603	0.111
World GDP lag4	-0.196	-2.340	0.021
Production lag1	-0.025	-1.547	0.124
Production lag2	-0.008	-0.518	0.605
Production lag3	-0.035	-2.345	0.021
Production lag4	-0.003	-0.206	0.837
Price lag1	-1.539	-1.661	0.099
Price lag2	-0.544	-0.436	0.663
Price lag3	0.206	0.170	0.865
Price lag4	1.790	2.122	0.036
Constant	1.267	0.344	0.731
Trend	0.005	0.660	0.510
Dependent variable: Copper production (percentage share)			
World GDP lag1	1.950	4.366	0.000
World GDP lag2	1.706	3.355	0.001
World GDP lag3	0.810	1.848	0.067
World GDP lag4	-0.258	-0.650	0.517
Production lag1	-0.287	-3.701	0.000
Production lag2	-0.258	-3.493	0.001
Production lag3	-0.374	-5.245	0.000
Production lag4	-0.245	-3.333	0.001
Price lag1	-13.522	-3.088	0.002
Price lag2	-2.990	-0.507	0.613
Price lag3	3.053	0.533	0.595
Price lag4	4.787	1.200	0.232
Constant	68.142	3.916	0.000
Trend	-0.184	-5.172	0.000
Dependent variable: Price of copper (logs)			
World GDP lag1	0.031	3.024	0.003
World GDP lag2	0.009	0.756	0.451
World GDP lag3	0.011	1.044	0.299
World GDP lag4	-0.002	-0.171	0.865
Production lag1	-0.004	-2.273	0.025
Production lag2	-0.002	-1.122	0.264
Production lag3	-0.001	-0.597	0.552
Production lag4	-0.001	-0.604	0.547
Price lag1	0.850	8.366	0.000
Price lag2	-0.164	-1.198	0.233
Price lag3	0.063	0.474	0.636
Price lag4	0.086	0.929	0.355
Constant	1.130	2.801	0.006
Trend	-0.002	-2.811	0.006

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
	(6.383)	(0.917)	(0.185)
Production	1.298	4.805	5.488
	(1.602)	(4.295)	(3.930)
Price	0.102	-0.091	0.105
	(1.859)	(-2.990)	(5.100)

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 standard errors are 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	4.002	0	0
	(2.623)	—	—
Production	1.394	5.496	0
	(0.714)	(3.919)	—
Price	1.744	-0.818	0.633
	(1.785)	(-2.378)	(3.958)

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 standard errors are 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 share)			
World GDP lag1	0.265	2.762	0.007
World GDP lag2	0.130	1.289	0.199
Production lag1	0.019	0.665	0.507
Production lag2	0.017	0.649	0.517
Price lag1	-0.466	-0.500	0.618
Price lag2	0.341	0.405	0.686
Constant	1.173	0.522	0.602
Trend	0.011	2.229	0.027
Dependent variable: Lead production (percentage share)			
World GDP lag1	0.958	3.102	0.002
World GDP lag2	-0.457	-1.409	0.161
Production lag1	0.039	0.426	0.670
Production lag2	0.031	0.363	0.717
Price lag1	4.933	1.645	0.102
Price lag2	-4.592	-1.695	0.092
Constant	1.321	0.183	0.855
Trend	-0.013	-0.814	0.417
Dependent variable: Price of lead (logs)			
World GDP lag1	0.031	3.257	0.001
World GDP lag2	-0.021	-2.053	0.042
Production lag1	0.001	0.303	0.763
Production lag2	0.004	1.422	0.157
Price lag1	0.888	9.597	0.000
Price lag2	-0.040	-0.474	0.636
Constant	0.782	3.506	0.001
Trend	-0.001	-1.871	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	0.127
	(7.052)	(-0.819)	(0.397)
Production	2.664	4.604	-0.344
	(3.192)	(6.399)	(-0.324)
Price	0.060	0.008	0.153
	(1.700)	(0.247)	(6.149)

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 standard errors are 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
	(0.620)	—	—
Production	4.666	5.028	0
	(1.584)	(0.834)	—
Price	0.732	0.209	1.010
	(0.365)	(0.241)	(0.304)

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 standard errors are 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 share)			
World GDP lag1	0.263	2.840	0.005
World GDP lag2	0.159	1.612	0.109
World GDP lag3	-0.020	-0.249	0.803
Production lag1	0.002	0.128	0.898
Production lag2	-0.008	-0.523	0.602
Production lag3	-0.026	-1.817	0.071
Price lag1	0.428	0.424	0.672
Price lag2	0.533	0.352	0.726
Price lag3	-0.705	-0.736	0.463
Constant	-1.056	-0.442	0.659
Trend	0.011	2.868	0.005
Dependent variable: Tin production (percentage share)			
World GDP lag1	1.664	3.278	0.001
World GDP lag2	0.418	0.773	0.441
World GDP lag3	-1.098	-2.527	0.013
Production lag1	-0.164	-1.961	0.052
Production lag2	-0.141	-1.766	0.080
Production lag3	-0.124	-1.583	0.116
Price lag1	-5.369	-0.971	0.333
Price lag2	15.807	1.906	0.059
Price lag3	-12.616	-2.406	0.017
Constant	20.780	1.588	0.115
Trend	-0.046	-2.115	0.036
Dependent variable: Price of tin (logs)			
World GDP lag1	0.007	0.866	0.388
World GDP lag2	-0.017	-1.930	0.056
World GDP lag3	0.001	0.140	0.889
Production lag1	-0.001	-0.727	0.468
Production lag2	-0.001	-0.733	0.465
Production lag3	-0.001	-0.586	0.559
Price lag1	1.262	14.265	0.000
Price lag2	-0.421	-3.174	0.002
Price lag3	0.098	1.166	0.246
Constant	0.466	2.225	0.028
Trend	0.000	0.316	0.753

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	1.507	0.532	-0.390
	(5.824)	(1.469)	(-0.911)
Production	0.376	8.364	3.322
	(0.317)	(6.501)	(1.294)
Price	0.097	-0.050	0.094
	(2.219)	(-1.444)	(3.575)

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 standard errors are 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	2.981	0	0
	(3.975)	—	—
Production	0.575	7.589	0
	(0.258)	(4.231)	—
Price	1.141	-1.139	1.525
	(1.137)	(-1.494)	(2.727)

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 standard errors are 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 share)			
World GDP lag1	0.333	3.432	0.001
World GDP lag2	0.151	1.497	0.137
World GDP lag3	-0.017	-0.209	0.835
Production lag1	-0.017	-1.029	0.305
Production lag2	0.024	1.420	0.158
Production lag3	-0.028	-1.776	0.078
Price lag1	0.814	0.964	0.337
Price lag2	-1.911	-1.654	0.100
Price lag3	1.247	1.511	0.133
Constant	-0.115	-0.039	0.969
Trend	0.010	2.067	0.041
Dependent variable: Zinc production (percentage share)			
World GDP lag1	1.285	2.629	0.010
World GDP lag2	-0.077	-0.151	0.880
World GDP lag3	-1.052	-2.532	0.012
Production lag1	-0.085	-0.100	0.319
Production lag2	-0.104	-1.245	0.215
Production lag3	-0.113	-1.455	0.148
Price lag1	-2.860	-0.673	0.502
Price lag2	-2.627	-0.451	0.652
Price lag3	4.647	1.118	0.266
Constant	13.170	0.876	0.383
Trend	-0.036	-1.412	0.160
Dependent variable: Price of zinc (logs)			
World GDP lag1	0.025	2.415	0.017
World GDP lag2	-0.001	-0.098	0.922
World GDP lag3	-0.008	-0.878	0.382
Production lag1	-0.005	-2.555	0.012
Production lag2	0.001	0.472	0.637
Production lag3	-0.001	-0.596	0.552
Price lag1	1.064	11.846	0.000
Price lag2	-0.563	-4.581	0.000
Price lag3	0.337	3.834	0.000
Constant	0.890	2.799	0.006
Trend	-0.001	-1.777	0.078

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	1.622	0.163	-0.142
	(7.054)	(0.860)	(-0.390)
Production	3.447	7.449	0.800
	(3.212)	(4.847)	(0.483)
Price	0.080	-0.014	0.154
	(1.820)	(-0.394)	(5.597)

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 standard errors are 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	3.149	0	0
	(3.976)	—	—
Production	2.555	5.888	0
	(1.801)	(5.040)	—
Price	0.731	-0.256	0.952
	(1.749)	(-1.071)	(3.056)

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 standard errors are in brackets. Maximum likelihood estimation, scoring Aagorithm (see Amisano and Giannini (1992)).

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

	Coefficient	**t-statistic**	**t-probability**
Dependent Variable: World GDP (percentage share)			
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 share)			
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 standard errors are 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 standard errors are 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 5 Sensitivity analysis

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	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	46	12	42	38	21	40	33	23	43
Zinc	LR	1841-2010	London	CPI	3	21	1	79	30	4	66	32	4	64
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	61
Tin	SR	1841-2010	London	CPI	3	14	0	85	11	3	86	8	4	88
Zinc	SR	1841-2010	London	CPI	3	9	4	86	21	2	77	22	2	76
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	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	4	50
Tin	LR	1900-2010	London	CPI	3	49	29	22	36	41	22	30	43	27
Zinc	LR	1900-2010	London	CPI	3	39	9	52	49	12	39	50	12	38
Cr. Oil	LR	1900-2010	Int.	CPI	2	49	33	18	43	34	23	43	34	23
Copper	LR	1925-2010	London	CPI	4	38	5	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	67	22	11	52	33	15	33	34	22
Zinc	LR	1925-2010	London	CPI	3	35	4	61	53	12	36	57	11	32
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 24: 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	13	3	84	13	7	80	12	8	81
Tin	LR	1841-2010	London	PPI	3	33	16	51	24	28	48	20	30	50
Zinc	LR	1841-2010	London	PPI	3	18	4	77	17	4	79	18	4	77
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 25: 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 26: Forecast error variance decomposition for the baseline specification using New York instead of London prices.

150 years of boom and bust –
What drives mineral commodity prices?

Martin Stürmer

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Bonn, February 2013 Martin Stürmer

Abstract

This paper examines the dynamic effects of demand and supply shocks on mineral commodity prices. It provides empirical insights by using annual data for the copper, lead, tin, and zinc markets from 1840 to 2010. I identify structural shocks by using long-run restrictions and compare these shocks to narrative historical evidence about the respective markets. Long-term price fluctuations are mainly driven by persistent demand shocks. Supply shocks exhibit some importance in the tin and copper markets due to oligopolistic market structures. World output-driven demand shocks have persistent, positive effects on mineral production. Long-term linear trends are statistically insignificant or significantly negative for the examined commodity prices. My results suggest that the current price boom is temporary but not permanent. Commodity exporting countries should prepare for a downswing of prices, while commodity importing countries should not fear for the security of supply of these widely used mineral commodities.

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Abbreviations

AKI	Akaike Information Criterion
CIPEC	Intergovernmental Council of Copper Exporting Countries
CPI	Consumer Price Index
BGR	Federal Institute for Geosciences and Natural Resources
GDP	Gross Domestic Product
LME	London Metal Exchange
mt	metric tons
PPI	Producer Price Index
VAR	Vector Autoregressive

1 Introduction

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

However, the 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 so focus on the supply side (Arrow / Chang 1982; Fourgeaud et al. 1982; Cairns / Lasserre 1986). Competitive storage mod-els usually interpret shocks as supply driven, but ultimately leave the source of shocks open. (Gustafson 1958a, b; Wright / Williams 1982; Cafiero et al. 2011). Another strand of literature on the subject stresses the role of storage in the presence of expected supply shortfalls in explaining price fluctuations (Alquist / 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.

What empirical work there is tends to focus on the oil market. According to Kilian (2009) and Kilian and Murphy (2012), fluctuations in the price of oil are driven mainly by demand shocks due to the global business cycle. In contrast, Hamilton (2008) stresses the role of supply shocks as a driver of crude oil prices. Thomas et al. (2010) find that a combination of supply and demand shocks determines the price of oil. Pindyck and Rotemberg (1990) claim that such macroeconomic variables as inflation and money supply help to explain the concurrent movements of various commodity prices. In the same direction, Belke et al. (2012) present empirical evidence that monetary aggregates drive various commodity price indices. Frankel and Rose (2010) find that, while global output and inflation have positive effects on the prices of several agricultural and mineral commodities, they are outstripped by volatility and inventories. Regarding storage models, Deaton and Laroque (1992, 1996) show that supply shocks and storage are not sufficient to explain price fluctuations and autocorrelation of commodity prices. They come to the conclusion that "demand shocks are a more plausible source of price fluctuations than has usually been supposed in the literature" (Deaton / Laroque 1996, 899). Cafiero et al. (2011) use a different estimation methodology and find empirical evidence in favour of the predictions of the empirical storage model.

This paper identifies the dynamic effects of demand and supply shocks on mineral commodity prices from 1840 to 2010. It covers a far longer time period than most previous work, thus allowing me to include a long series of boom and bust in prices. Commodities have always shown greater price volatility than manufactures (Jacks et al. 2011), and booms and busts are not a new phenomenon (see, e.g., Cuddington and Jerrett, 2008). In contrast to Erten and Ocampo (2012), who examine "super-cycles" of a metal price index over the period from 1865 to 2009, I am able to include data on the supply side of the mineral commodity markets examined here and hence to pin-down the contribution of shocks to the fluctuation of prices. In addition, I provide a detailed historical account for each price.

To obtain empirical evidence from such a long time period, I use a new set of annual data which includes prices, world production of copper, lead, tin, zinc, and crude oil, and world

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

GDP. I chose copper, lead, tin, and zinc because they were traded on the London Metal Exchange and its predecessors as fungible and homogeneous goods in an integrated world market over the long period considered here. The four mineral commodities studied exhibit a substantial track record in industrial use and are still among the top twenty-five in value of world production. Hence, these four mineral commodity markets exhibit long-term characteristics that other mineral commodities such as iron ore or coal have only gained in recent times. To ease comparison to the literature, I also present regression results for the crude oil market. In contrast to the other four mineral commodities, the market has undergone major structural changes (Kilian / Vigfusson 2011; Dvir / Rogoff 2010) which make it difficult to obtain regression results that are robust across sub-periods.

I use a structural vector autoregressive (VAR) model to decompose demand and supply shocks to fluctuations in the real price of the commodity concerned. To do so, I assume the existence of three different types of shock to commodity prices: “supply shocks”, e.g., a disruption in physical production due to strikes; “world output-driven demand shocks”, which include shocks in global demand for all commodities due to, e.g., an unexpected strong growth of world output; and “other demand shocks”. The latter include all other shocks that have no correlation with the aforementioned two shocks. I interpret them as mainly capturing unexpected changes in inventories driven by the market power of producers, government stocking programs, and changing expectations of consumers. My identification is based on long-run restrictions, which allows me to leave short-run relationships unrestricted.

My paper is to my knowledge the first to provide long-term evidence on demand and supply shocks in mineral commodity markets. The main conclusion drawn in this paper is that price fluctuations of the four mineral commodities studied here were basically driven by demand shocks rather than by supply shocks over the period from 1840 to 2010. My results point to the importance of models that take into account demand shocks due to world output like in Kilian (2009) and in Kilian and Murphy (2012). Dvir and Rogoff (2010), Mitraille and Thille (2009), Bodenstein and Guerrieri (2011), and others have only recently begun to develop such theoretical models.

My analysis suggests that extensions of the seminal Hotelling (1931) model such as those by Arrow / Chang (1982), Fourgeaud et al. (1982), and Cairns / Lasserre (1986) which explain price fluctuations by supply shocks must be rethought. It also questions the usual interpretation of shocks in competitive storage models (Gustafson 1958a, b; Wright and Williams, 1982), which views supply shocks as a key to explaining commodity price fluctuations. Supply shocks 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 / Thille 2006).

In contrast to the classical competitive storage models, my findings point to inventories as a source of fluctuations rather than a calming agent. My results provide long-term evidence in support of Alquist and Kilian (2010) and others who maintain that storage in the presence of expected supply shortfalls explains price fluctuations. Narrative evidence in this paper, however suggests that shocks due to changes in inventories are rather driven by producer cartels and government stockpiling, and only in recent times by “precautionary” behaviour of consumers or investors in the markets examined here.

Impulse response functions show that “world output-driven demand shocks” have had a large and statistically significant effect on the prices of all the commodities considered, reaching their peak after one or two years. They persist for five to ten years. “Other demand shocks” have direct and significant effects on all commodities and are quite persistent. Supply shocks exhibit a significant impact only on the prices of tin and copper. Whereas world output-driven demand shocks have a strong, significant, persistent and positive effect on the production of copper, lead and tin, they have a positive, but only insignificant effect on the production of zinc.

In contrast to the other mineral commodities examined in this study, the results for 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 / Rogoff, 2010) and the strong change of importance of oil in the economy over time. 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, whereas they 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.

My results have important policy implications both for commodity exporting and commodity importing countries. For optimal fiscal and macroeconomic policy responses in commodity exporting, developing countries, it is important to know first whether a price change is temporary or permanent, and second to identify the driving source behind the price change (see IMF 2012). My results suggest that the current price boom is temporary rather than permanent: the long-term trends are significantly negative or statisti-cally insignificant for the commodities examined. Hence, commodity exporters should take a countercyclical 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 fis-cal 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 market but are ineffective, as history shows, in increasing prices over the long-run.

For countries which import mineral commodities, my results indicate that apprehensions about the security of the supply are rather exaggerated in the light of historical evidence 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, while 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 introduce my interpretation of the shocks studied here. In section 3 I describe the construction of my data set. Section 4 focuses on the econometric model and the scheme used to identify and distinguish the different structural shocks. In sections 5 and 6, I present empirical results and robustness checks for copper, lead, tin, and zinc. Section 7 gives empirical results and robustness checks for the case of crude oil. Section 8 offers conclusions.

2 Interpretation of shocks to mineral commodity prices

I classify the key determinants of mineral commodity prices close to Kilian (2009). This allows me to distinguish three shocks, notably “world output-driven demand shocks”, “supply shocks” and “other demand shocks”.

I define “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 the world economy. They thus also 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. “World output-driven demand shocks” result from both non-persistent aggregate demand shocks (e.g., monetary policy shocks) and persistent aggregate supply shocks (e.g., productivity changes).

“Supply shocks” are shocks to the production of mineral commodities due to unexpected changes in production caused by cartels, strikes, or natural catastrophes.

I do not directly include “other demand shocks” in this model due to missing long-term data on inventories and world use of the mineral commodities. Instead, controlling for “world output-driven demand shocks” and “supply shocks” allows me to pin down the “other demand shocks” as the residual of a structural dynamic simultaneous-equation model. They mainly reflect changes in the demand for inventories of mineral commodities which stem from three different sources: first, government stocking programs, second, producers with market power who increase their inventories in an attempt to increase prices, and finally, shifts in expectations of the downstream processing industry about the future supply and demand balance (see Kilian 2009; Kilian / Murphy,2012, on the last point).

As “other demand shocks” capture all shocks that are uncorrelated to “world output-driven demand shocks” and “supply shocks”, they also include unexpected changes in the intensity of use of the respective mineral commodity in the production of world output. The intensity of use reflects the quantity of a mineral commodity which an economy needs to produce one unit of output. The intensity of use is driven by several factors: first, technical improvements that either decrease or increase the quantity of a mineral commodity used to produce a specific good, second, substitution by other materials, third, changes in the structure of world output (e.g., a higher share of services), fourth, saturation of markets, and finally, government regulations that change the use of materials (for example the phase-out of lead additives in gasoline see (Cleveland / Szostak, 2008). However, all of these processes are rather longterm, especially on the world level. Even government regulation, such as that imposed on lead additives, has become set in a continuous process of phasing-out over several decades. Narrative historical evidence suggests that “other demand shocks” capture unexpected changes in inventories rather than changes in the intensity of use. The latter are rather captured in the linear trends in the regressions.

3 A new data set

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 LME was the principal price setter in these non-ferrous metals markets outside of the U.S. during most of the study period (Schmitz 1979; Rudolf Wolff & Co Lt. 1987; Slade 1991) . The prices are in British-£ for most of the period covered in this study. Since the middle of the 1970s they have been given in U.S.-$, and I have transformed them to British-£ by using annual exchange rates. For robustness checks I have also collected U.S.-American prices. I obtained nominal world market prices for crude oil from British Petroleum (2011). This price series reaches back to 1861. Please note that there have been some gradual changes in the quality of products over time.

Following Krautkraemer (1998) and Svedberg / Tilton (2006), I deflate all nominal prices by the respective consumer price indices (CPI) for the U.K. and the U.S. I also 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.

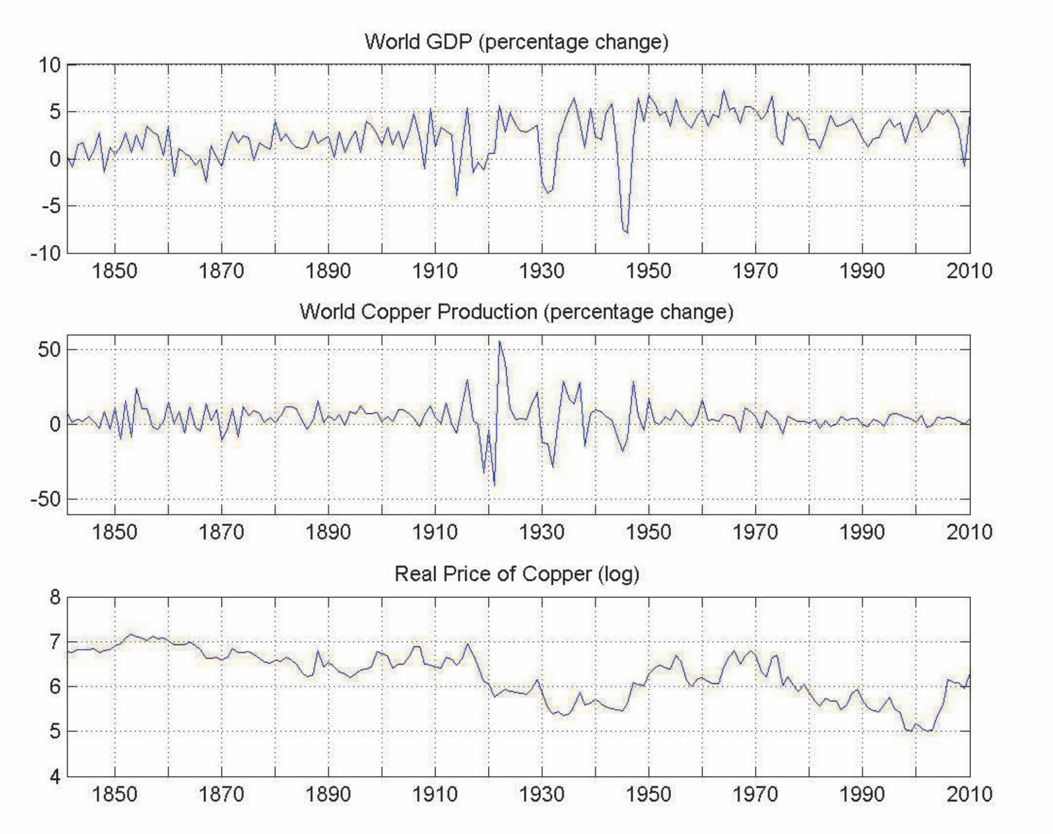
A common definition for the existence of a world market is that prices for a homogeneous good strongly co-move across different areas of the world. This implies that price movements are in accordance with the law of one price, even though the levels of prices might differ due to transportation costs or trade barriers. Klovland (2005) shows that British and German markets for copper, lead, tin, and zinc were integrated from 1850 until World War I, whereas price gaps for pig iron and coal remained quite significant due to trade policies and high transport costs. O'Rourke and Williamson (1994) find a strong convergence of U.S. and British copper and tin prices between 1870 and 1913. Finally, Stürmer and von Hagen (2012) provide evidence from British, U.S., and German price data for copper, tin, and zinc from 1850 to 2010.

Unfortunately, there is to my knowledge no empirical evidence regarding historical integration of the oil market. However, 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. In the 1870s and 1880s it was even the 4th largest U.S. export in value. By the 1880s competition was already strong from Russian oil. Hence, I assume in the following sections that world oil markets have been as integrated over time as the non-ferrous metal ones described above and leave it to future research to find statistical evidence for this assumption.

According to Findlay and O'Rourke (2007), commodity markets disintegrated during World Wars I and II. Price and supply controls for mineral commodities tend to characterize wartime economies (see Backman / Fishman (1941) regarding the example of Great Britain). Unfortunately, no systematic study of price convergence for the above metals in the inter-war period has been carried out. I account for the disintegration of world markets during the two World War periods by using yearly dummies for the war period and the three consecutive years. For the period after World War II until today, Labys (2008) finds evidence for strong market integration.

I have assembled data on the world production of the four 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 secondary materials. However, the differentiation between primary and secondary materials

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



Notes: For other mineral commodities see the Appendix.

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.

In contrast to Kilian (2009) and Kilian and Murphy (2012) I do not create a freight rate index to measure global economic activity but use world GDP from Maddison (2010) and The Conference Board (2012). Unfortunately, Maddison's data set only provides annual world GDP data from 1950 onwards. Therefore, I sum up country based annual data. For those years where country based annual data is missing, I generally interpolate the data with linear trends. For European countries and Western offshoots, I compute their respective shares of output related to neighboring countries, where data is available. I then interpolate these shares and multiply them with the 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.

4 Identification

I use a three-variable, structural VAR model with long-run restrictions to decompose unpredictable changes in the real mineral commodity prices into three mutually uncorrelated shocks, notably “world output-driven demand shocks”, “supply shocks”, and “other demand shocks”. 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, wheras I do so at the level of a specific commodity market.

The basic idea of the variance decomposition is to find what amount of information each variable, notably world total output 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 total output 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 price. D_t denotes a matrix of deterministic terms, notably a constant, a linear trend, and annual dummies during World War I and II periods and the three years immediately after. The structural VAR representation is

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

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

To compute the structurally identified impulse responses, I estimate the contemporaneous impact matrix $C = A^{-1}B$ by $\hat{C} = \hat{\Phi}^{-1}\hat{\Psi} = \hat{\Phi}^{-1}\text{chol}[\hat{\Phi}\hat{\Sigma}_u\hat{\Phi}']$. Φ is the matrix of accumulated effects of the impulses, namely $\Phi = \sum_{s=0}^{\infty}\Phi_s = (I_K - \Gamma_1 - ... - \Gamma_p)^{-1}$. Ψ is the long-run impact matrix of structural shocks. We need $K(K-1)/2 = 3$ restrictions 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 mineral commodities and “other demand shocks” exhibit transitory but not permanent effects on world total output. These two shocks thus affect world total output 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 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" (see below) have no long-term effect on global real GDP. This assumption seems strong as one might argue that a reduction in inputs of a certain commodity might affect productivity and hence world total output 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 of relevance. 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 output 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 total world output. 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 global real GDP from the aggregate demand side. Even in the case of crude oil, Rasmussen and Roitman (2011) have shown that oil price shocks on a global scale exhibit only small and transitory negative effects on a slight majority of countries.

I do not distinguish between the different sources of "world output-driven demand shocks", be they transitory aggregate demand shocks due, e.g. to unexpected changes in unemployment, or persistent aggregate supply shocks due, e.g., to increases in productivity (see Blanchard and Quah, 1989). However, it is important to keep these different sources of "world output-driven demand shocks" in mind when it comes to explaining mineral commodity production.

Supply shocks

I define "supply shocks" 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 primary production of the respective commodity in the long-run. In contrast, price changes driven by "other demand shocks" exhibit only a transitory effect on world primary production. They hence affect only capacity utilisation of the extractive sector but not long term investment decisions. This is plausible, given the fact that expanding extraction and first-stage processing capacities exhibits high upfront costs and takes many years (Radetzki 2008; Wellmer 1992). This makes it likely that "other demand shocks" affect world primary production only in the short-term.

Other demand shocks

Other demand shocks encompass all innovations to the respective real mineral commodity price that are driven neither by the "world output-driven demand shocks" nor the "supply shocks". It hence captures all shocks that are uncorrelated to these two latter shocks. These in turn mainly capture changes in the demand for inventories due to government stocking programs, producer market power, and shifts in expectations of the downstream processing industry about the future supply and demand balance (see on the last point Kilian 2009; Kilian / Murphy 2012).

Overall, this methodology allows me to identify the effects of demand and supply shocks on mineral commodity prices and to estimate long-run price trends. Theoretical models make different predictions on the long term trends and the type of shocks that drive fluctuations in prices. The seminal Hotelling (1931) model predicts an increasing trend in prices, while it makes no statement on price fluctuations. Extensions of the Hotelling (1931) model such as those by Arrow and Chang (1982), Fourgeaud et al. (1982), and Cairns and Lasserre (1986) introduce the exploration of deposits which causes sudden price changes. Following this literature, I would expect "supply shocks" to mainly drive price fluctuations. These models predict different short term price trends, but mainly point to increasing trends in the long term.

Competitive storage models (Gustafson 1958a, b; Wright / Williams 1982) usually assume supply shocks as the source of uncertainty.[2] Storage smoothes these shocks intertemporally and explains the empirically observed autocorrelation in prices. Commodity storage models do not make a prediction concerning the trend. Based on this literature I would expect supply shocks to drive fluctuations in prices. Alquist and Kilian (2010) and Kilian and Murphy (2012) extent the storage model in a way that storage in the presence of expected supply shortfalls explains price fluctuations. These shocks would show up in the "other demand shocks" in our model. Finally, some scholars have explicitely modelled demand shocks. Dvir and Rogoff (2010) introduce persistent demand shocks to a competitive storage model. In this model storage amplifies rather than smoothes these shocks if supply is restricted. Mitraille and Thille (2009) endogenize production and therefore regard demand shocks as the source of uncertainty in a competitive storage model. Bodenstein and Guerrieri (2011) introduce several types of demand shocks in a two-country DSGE model. Overall, these models seem to suggest that demand shocks drive price fluctuations.

5 Empirical results

I employ ordinary least squares to consistently estimate the reduced-form coefficients of the VAR models of each of the four 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. For each mineral commodity, I first 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.

2 However, these models ultimately leave the source of shocks open, since shocks to demand and supply are "isomorphic" in the model setup (Dvir / Rogoff, 2010, 10).

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. The two figures are related as a positive structural shock drives upwards the curve of the cumulative effect of the shocks in the historical decomposition.

5.1 Copper market

My results show 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. 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).

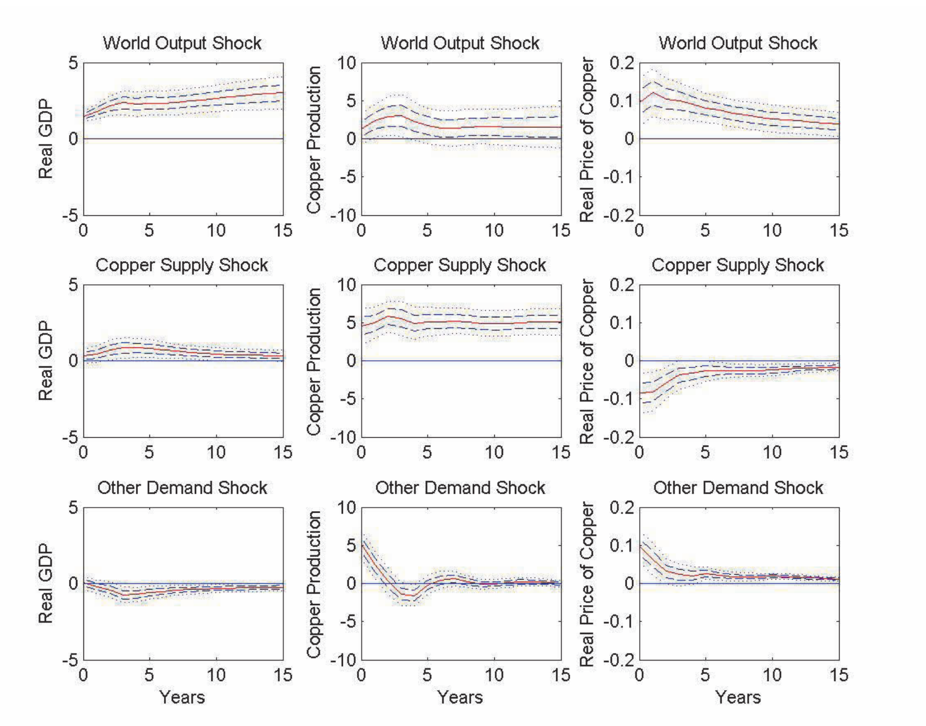
The impulse response functions in Figure 2 show that a positive "world output-driven demand shock" exhibits a strong, positive, and persistent effect on world GDP. It causes a positive significant increase in copper production that lasts for about three years. Finally, it triggers a major increase in the real price of copper for a maximum of 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 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.

In the late 1840s the price of copper was low owing to the British railway crisis from 1847 to 1848 (see Kindleberger / 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 / 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 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 American Civil War from 1861 to 1865, and the Overend-Gurney Crisis in 1866 and their respective economic aftermaths (see Kindleberger / Aliber 2011). At the same time, there was some

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



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.

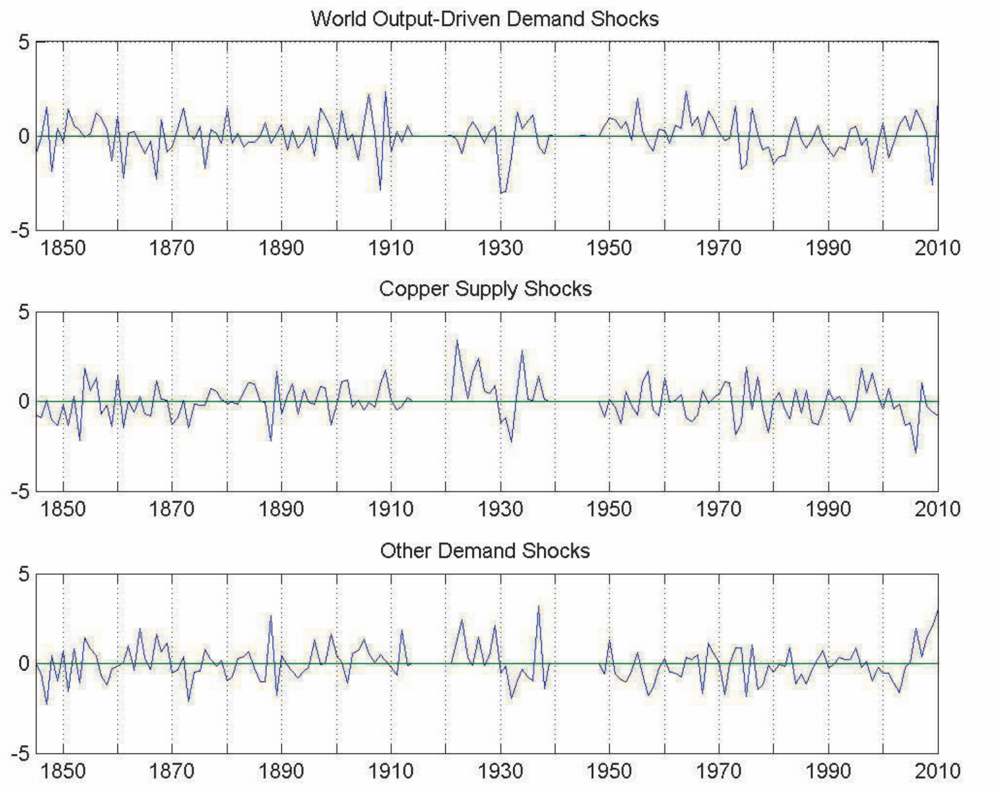
downward pressure caused by positive "supply shocks" due to the opening of new mines in Arizona and Michigan - despite the problems posed by the Civil War - and a substantial increase in production in Chile and elsewhere in the world, especially in the late 1860s (Richter 1927).

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 / Aliber 2011). Second, major, positive "supply shocks" drove prices down. Between 1875 and 1885, annual U.S. copper production rose by more than 500 per-cent. The Anaconda mine in Montana "proved fabulously rich and enormously productive" (Richter 1927, 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, 257). This explains the negative "supply shock" at that time.

In response, the new Secrétan copper syndicate, which controlled up to eighty percent of world production, became active from 1887 to 1889 (Richter 1927; Herfindahl 1959),

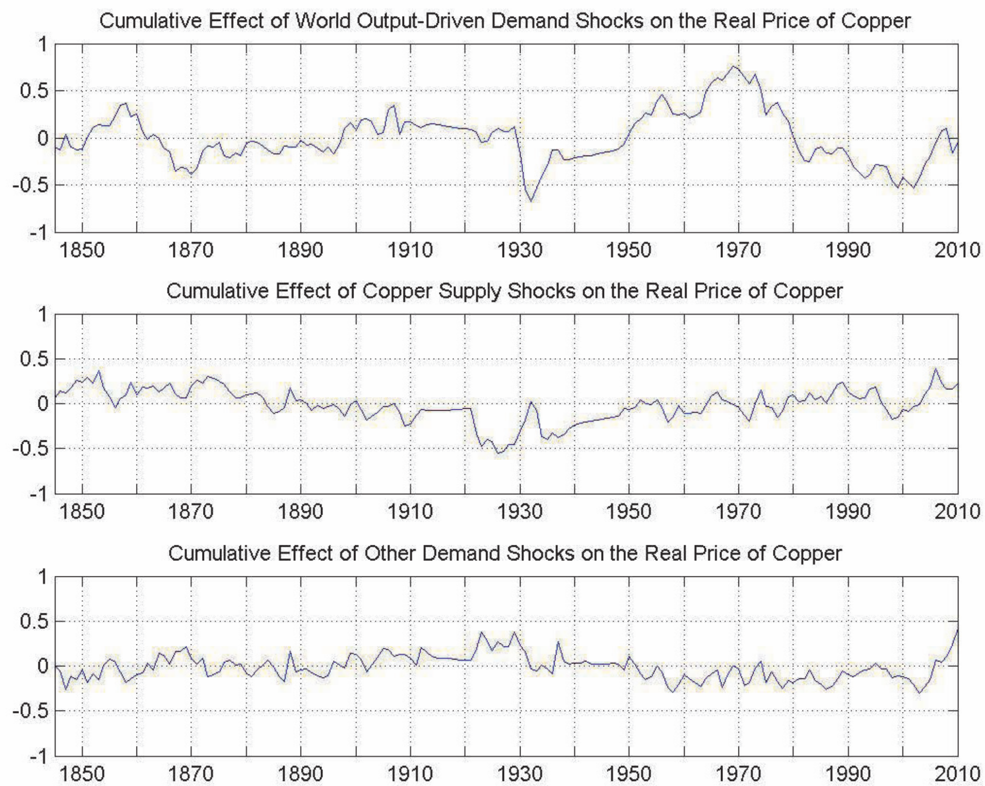
Figure 3: Historical evolution of structural shocks for copper



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 b ank, 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, 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 a financial crisis in the U.S as described by Kindleberger / Aliber (2011) (see also data provided by Crafts et al. 1989; NBER 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 and number of other firms tried to stabilize the price of copper by withholding stocks from the markets and restricting output (Herfindahl 1959, 81). This is also revealed 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, 83-91). These manipulations played a major part in the fluctuations in the price of copper, 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, 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, 278-81).

Figure 4: Historical decomposition of the real price of 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.

The price of copper stayed relatively flat during the 1920s, with a small peak in 1 929. 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 Association3. In 1917 world refined production totalled 1.4 million metric t ons. 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 cease. 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 (Herfindahl 1959, 93-4) in the early 1920s and later by the Copper Exporters Inc. (Herfindahl 1959, 100-6).

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, 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, 105). In 1935 the International Copper Cartel emerged and succeeded in driving up the price of copper in the late 1930s (Herfindahl 1959, 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 prices. 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. Volun-tary 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 produc-tion in 1975 aggravated the negative "supply shocks" (see Sachs 1999; Mardones et al. 1985). 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, 205), as is evident from the strong accumulative effects of "supply shocks" and "other demand shocks". On the other hand, the recessions 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

3 Please note that I have not included the three years after the First and Second World Wars in my regressions.

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 for 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 proveded 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 restriction output and by stocking. The evidence points to inventory changes by producer cartels, governments, and in the last years of investors as a key driver of "other demand shocks".

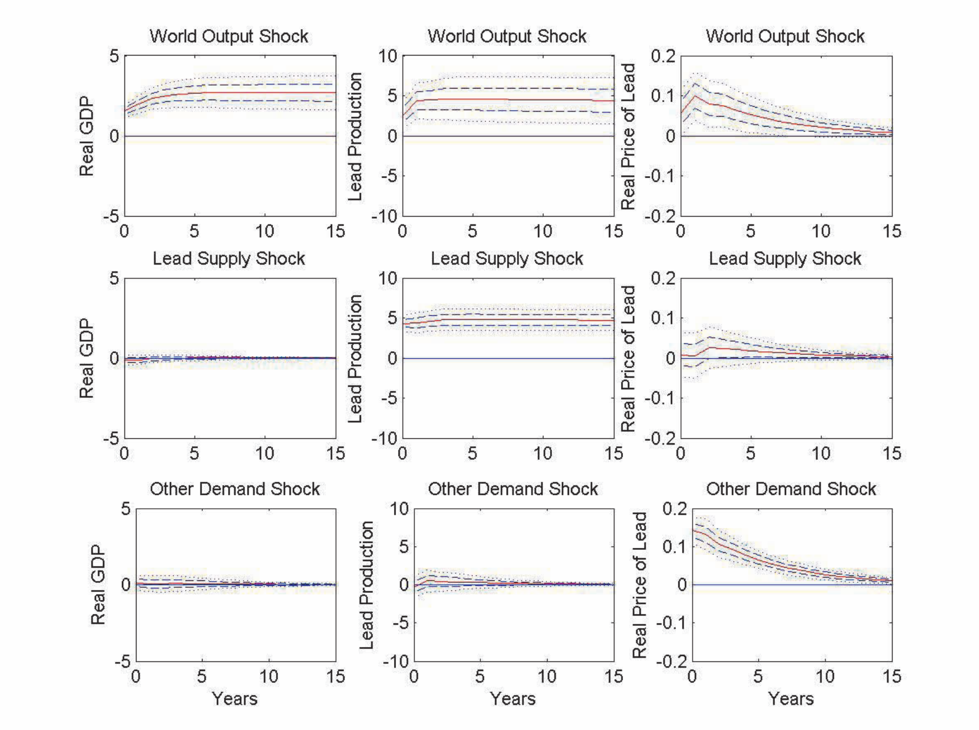
5.2 Lead market

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 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 country (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 function 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.

A positive unexpected shock to the supply of lead does not cause a significant change in world GDP, but does have a strong, significant, and persistent effect on world production of lead. It has a slightly positive, but insignificant effect on the real price of lead. This result is in line with my finding for zinc, where the effect of "supply shock" on the price is also insignificant. In the copper and tin markets, on the other hand, positive "supply shocks" have a strong and significant effect on price. I ascribe the difference to market structures. Copper and tin production are horizontally more concentrated than that of zinc and lead (BGR 2007; Rudolf Wolff & Co Lt. 1987). In addition, copper and tin tend to be mined in developing countries, while lead and zinc are mined mainly in industrialized countries that also use lead and zinc as manufacturing

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



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.

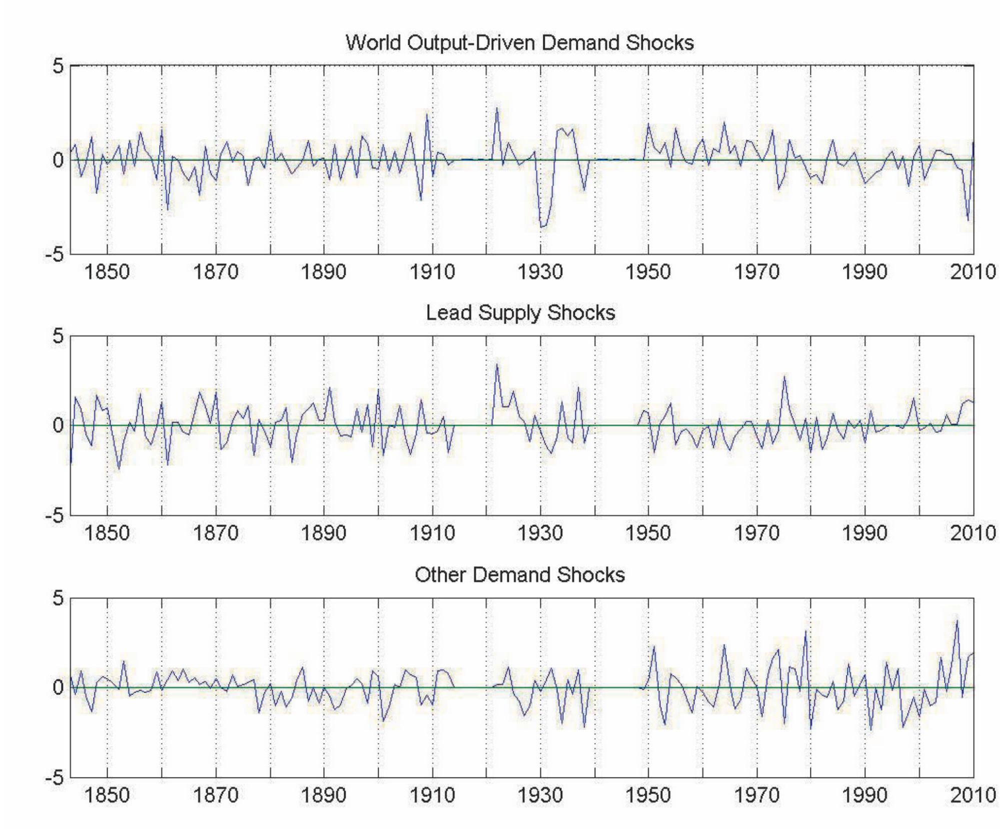
inputs (Rudolf Wolff & Co Lt. 1987; Schmitz 1979; BGR 2007). As a consequence, shocks to supply, in the form of coordinated production decreases by a cartell, for example, have an impact on copper and tin prices, but do not affect the zinc and lead markets.

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.

Lead price was driven mainly by world output-led demand shocks and "other demand shocks" in the period considered. Prices rose in the early 1850s and remained at this level for the next decade. Overall, prices remained relatively stable until the 1880s, compared to the other three mineral commodities examined. McCune-Lindsay (1893) comes to the conclusion that the price of lead was affected far less by a "twist of fate" (McCune-Lindsay 1893, 150). He also adds that it is impossible to find data on stocks that explain movements in the price of lead.

Unfortunately, not much is known about the lead market in the 19th century. "Other demand shocks" in the mid 1860s may have been due to the consider uncertainty in the market about the Austro-Prussian War that probably affected trade in zinc from its main production sites in Silesia. Moreover, according to (Gibson-Jarvie 1983) the zinc industry has always been prone to producer cartels in the main producing country Germany, where "the cartel 'rationale' generally was both established and indeed encouraged...." (Gibson-Jarvie 1983, 73). Throughout the last decade of the 19th century there were “repeated rumours in circulation as to a potential zinc cartel (...) sufficiently strong as to have an unsettling effect on prices” (Gibson-Jarvie 1983, 73). However, as producers were unable to agree on or sustain production limits, these rumours faded again (Gibson-Jarvie 1983, 73). In its account of copper prices in 1900 and 1901, (Metallgesellschaft 1904) mentions that the Lead Trust, a large cartel in the U.S., limited its production, and stocks increased so sharply that prices rose for a time (Metallgesellschaft 1904). Overall, these ups and downs in cartel action may explain the “other demand shocks” that drove up prices in the mid 1890s, then vanished and had a strong positive impact on prices again in the mid 1910s.

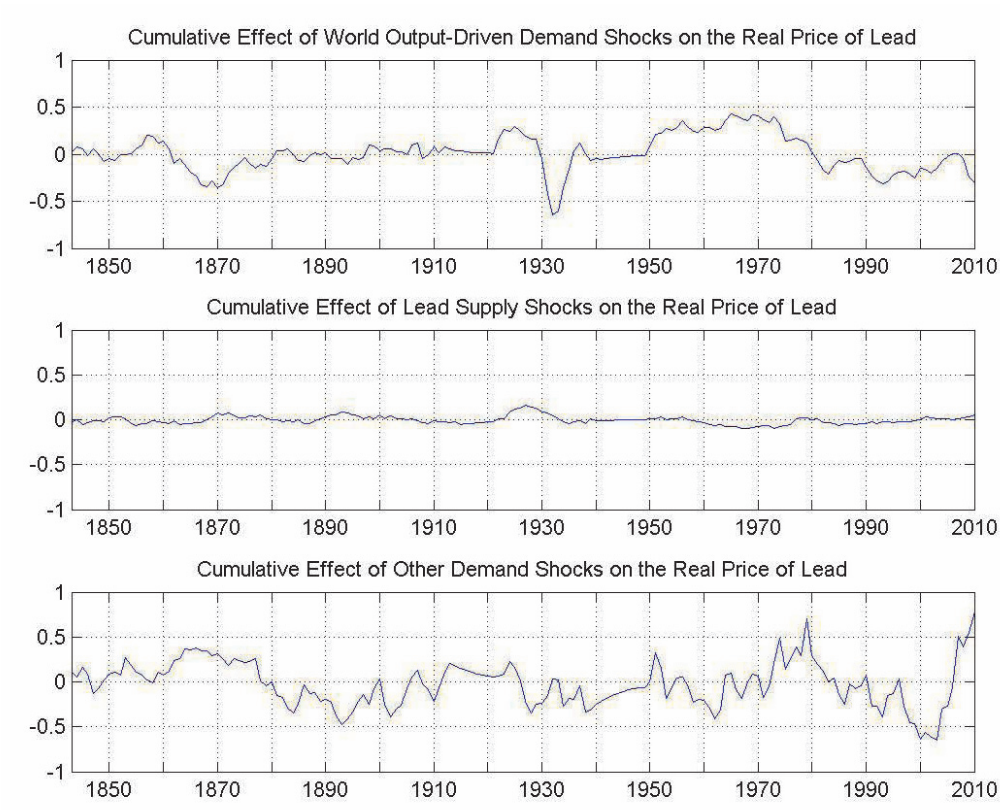
Figure 6: Historical evolution of structural shocks for lead



In 1909 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 used stocks to withhold lead from the market (Gibson-Jarvie 1983). The “other demand shocks” show that,as a historical account claims, the Association was relatively successful in driving up prices from 1910 to 1913 (Gibson-Jarvie 1983).

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

Figure 7: Historical decomposition of the real price of lead



1983, 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 (Gibson-Jarvie 1983; Hughes 1938).

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 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, 684). In 1951 the U.S. government set a price ceiling (see Bishop and den Hartog 1954, 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 wordwide 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 as the "other demand shocks" that drove the price up rather than supply shortages. There were also 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 these 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 to the phasing out of lead from many domesticappliances, 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 encompasses shocks to the use of lead due to environmental regulation in the 1970s and 1980s.

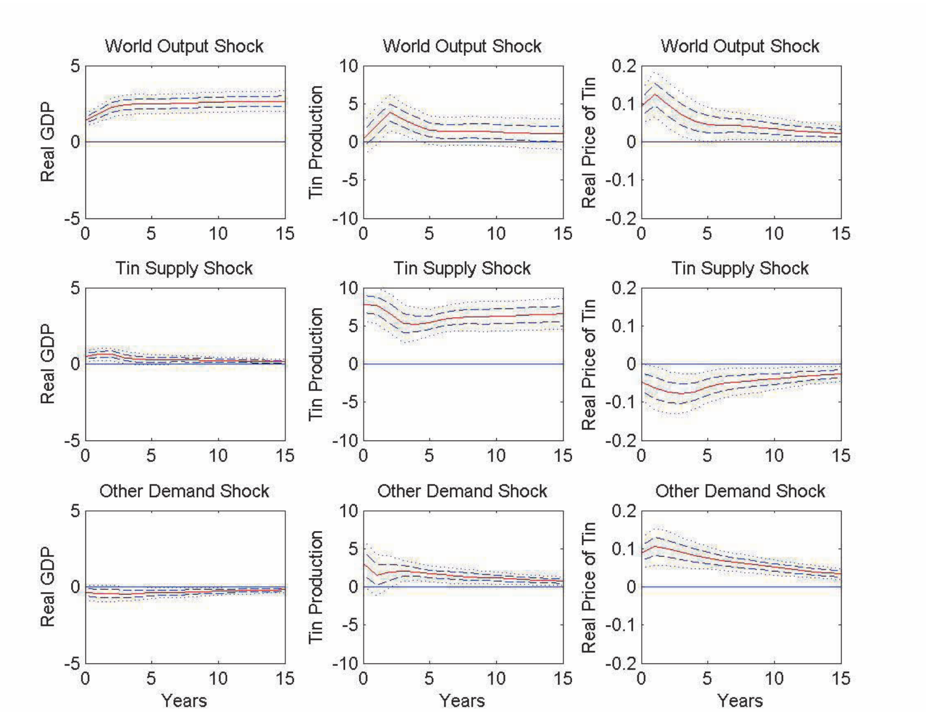
5.3 Tin market

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 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, 1)

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, 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.

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

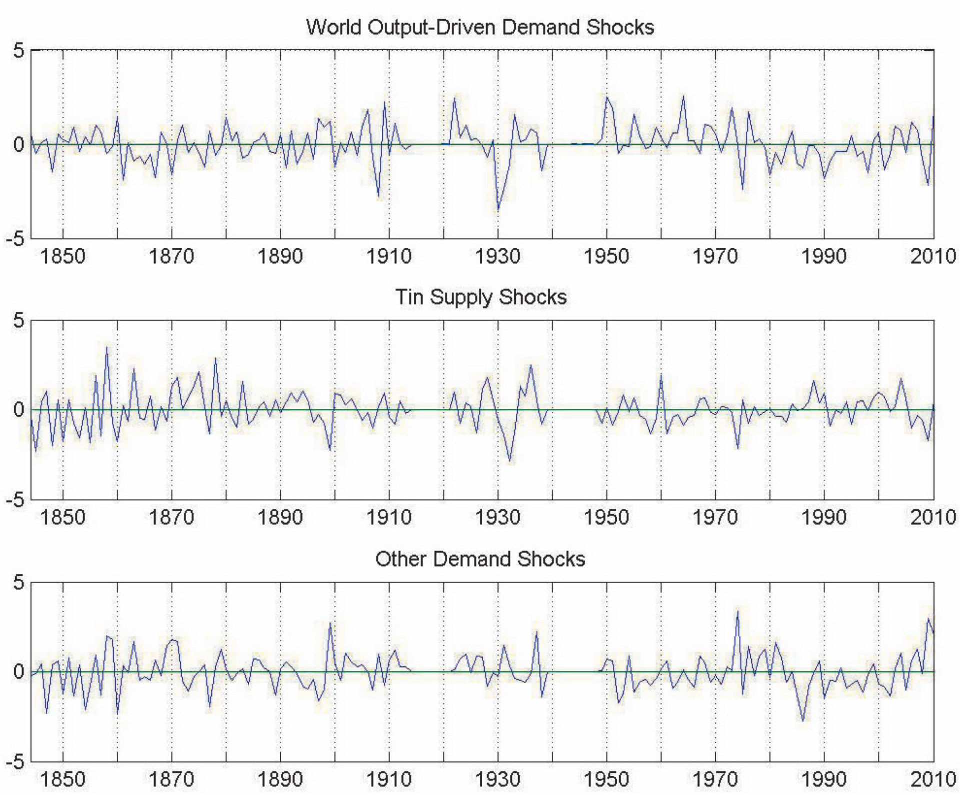


Notes: Point estimates with one- and two-standard error bands based on Model (1). I use accumulated impulse response functions for the shocks on world mineral commodity production and world GDP to trace out the effects on the levels of these variables.

Finally, I find that positive “other demand shocks” have no statistically significant impact on world GDP but exhibit a positiv rather small effect on tin production which turns statistically significant about three years after the shock hit. Due to my long-run restrictions, the effects levels off over time. An unexpected increase in “other demand” leads to a strong and positive increase of the real price of tin that keeps on being statistically significant for more than fifteen years.

According to my findings, these fluctuations are driven mainly 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 / 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

Figure 9: Historical evolution of structural shocks for tin

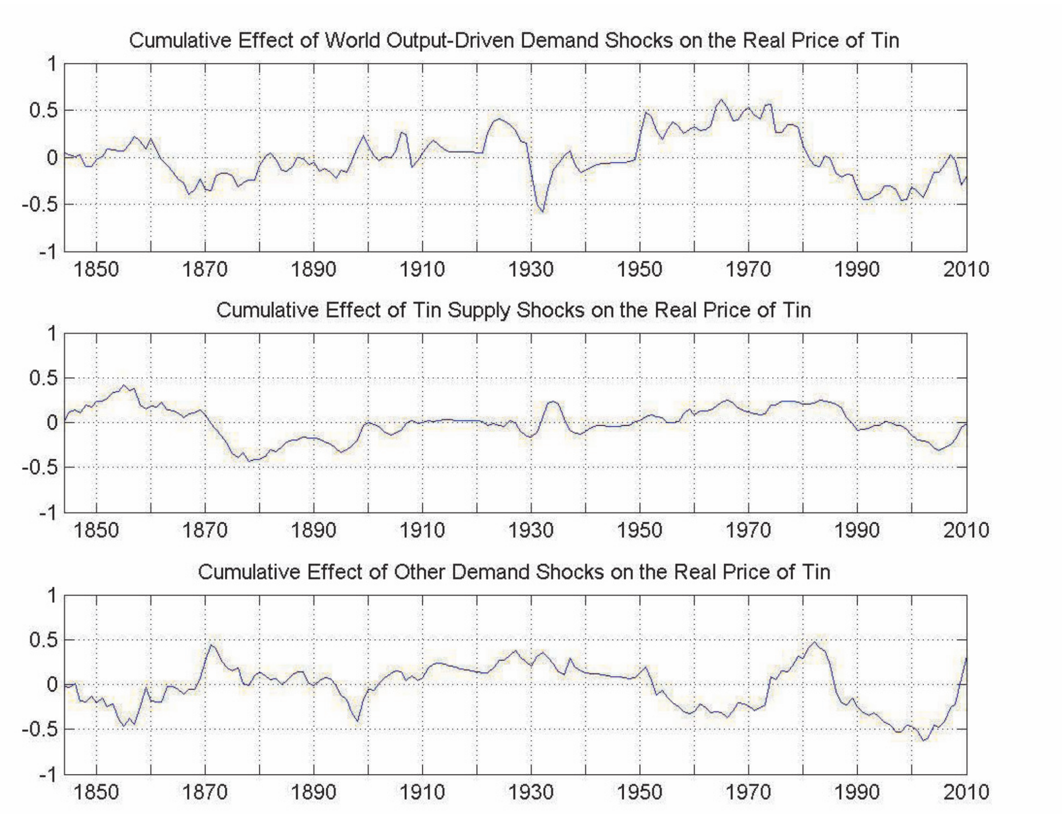


Neumann 1904, 251-2). "Other demand shocks" also exerted downward pressure on the price, but their sources are not identifiable from the literature.

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. 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 / 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). Britain intervened and took control of important parts of the Malayan peninsual 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 stockholding 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 significantincrease 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".

Figure 10: Historical decomposition of the real price of tin



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; NBER 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; NBER 2010).

Price fluctuations in the inter-war period were influenced mainly by the economic recovery after the First World War, the effects of the Great Depression and the attempts to form cartels. In 1921 the governments of the Federated Malay States and the Dutch East Indies establishd the Bandoeng Pool and agreed to stabilise the price of tin by jointly managing inventories (Thoburn 1994). The Bandoeng Pool controlled more than 50 percent of world production at the time (Thoburn 1994, 77). From 1921 to 1923 it withheld some fifteen percent of world tin production from the market and sold it gradually when prices rose mid 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, 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 unsuccesssful, 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 programme. 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 with 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 / Schink 1976). From an examination of “other demand shocks” it seems that the downward pressure of subsequent releases from the U.S. stockpiling programme 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 levelled-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 been due not only by restocking at producers and consumers, but also, according to industry obsevers, to stockpiling by investment funds as attribute (U.S. Geological Survey 2011b).

Overall, my results provide evidence that fluctuations in the tin price 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 build-up and collapse of the International Tin Agreement which influenced the price strongly over several decades.

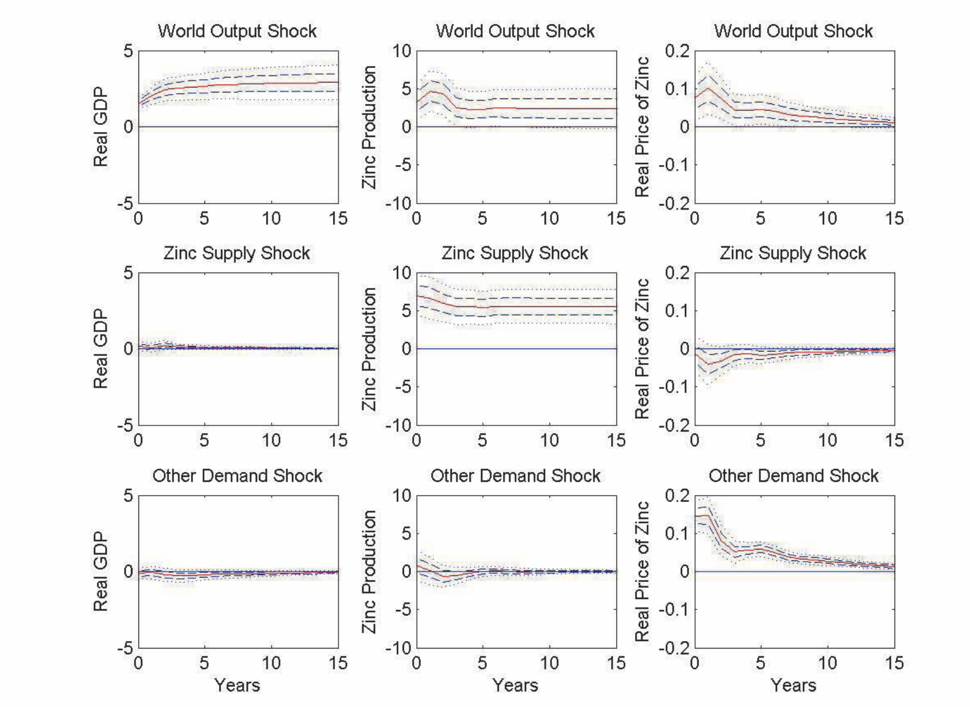
5.4 Zinc market

My results show that "world output-driven demand shocks" and "other demand shocks" are the main drivers of fluctuations in the real price of z inc. As it is the case for lead, zinc is basically produced in industrialised 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 behaviour of the zinc market is very similar to that of the lead. An unexpected rise in demand due to an increase in world output is causing 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.

An unexpected increase in zinc supply does not have an effect on world GDP, but has a string positive impact on zinc production, as is to be expected 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

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



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.

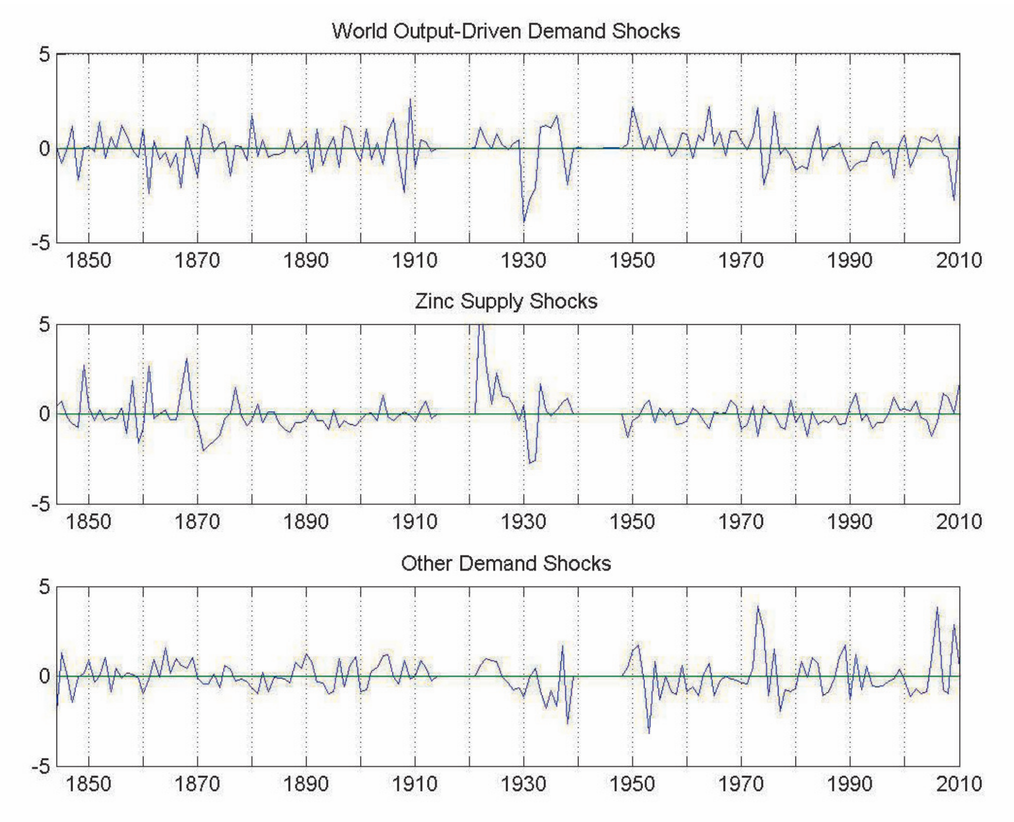
Wolff & Co Lt. 1987; Schmitz 1979; BGR 2007). As a consequence, shocks to supply in the form of coordinated production decreases by a cartell, for example, have an impact on copper and tin prices, without affecting the zinc and lead markets.

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. Prices rose sharply in the 1850s and peaked in 1857, driven mainly by the accumulative effects of "positive output-driven demand shocks" as the world economy boomed in the 1850s (see Kindleberger / 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 / 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. 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 stocks. I leave it to future research to delve deaper into the history of the zinc market around that time.

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 / Walters 1968). These attempts failed, since local production decreases were offset by production elsewhere (Jolly 1997; Cocks / Walters, 1968). As a result, negative "other demand shocks" in combination with "world output-driven demand shocks" caused by the Long Depression exerted downward pressure on prices, which reached their lowest level in the mid-1880s.

Figure 12: Historical evolution of structural shocks for zinc



As a reaction to the low prices in the 1880s, major European producers joined the "first significant international zinc cartel" (Jolly 1997, 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 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.

Prices 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 smeltering plants 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 / Walters 1968, 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).

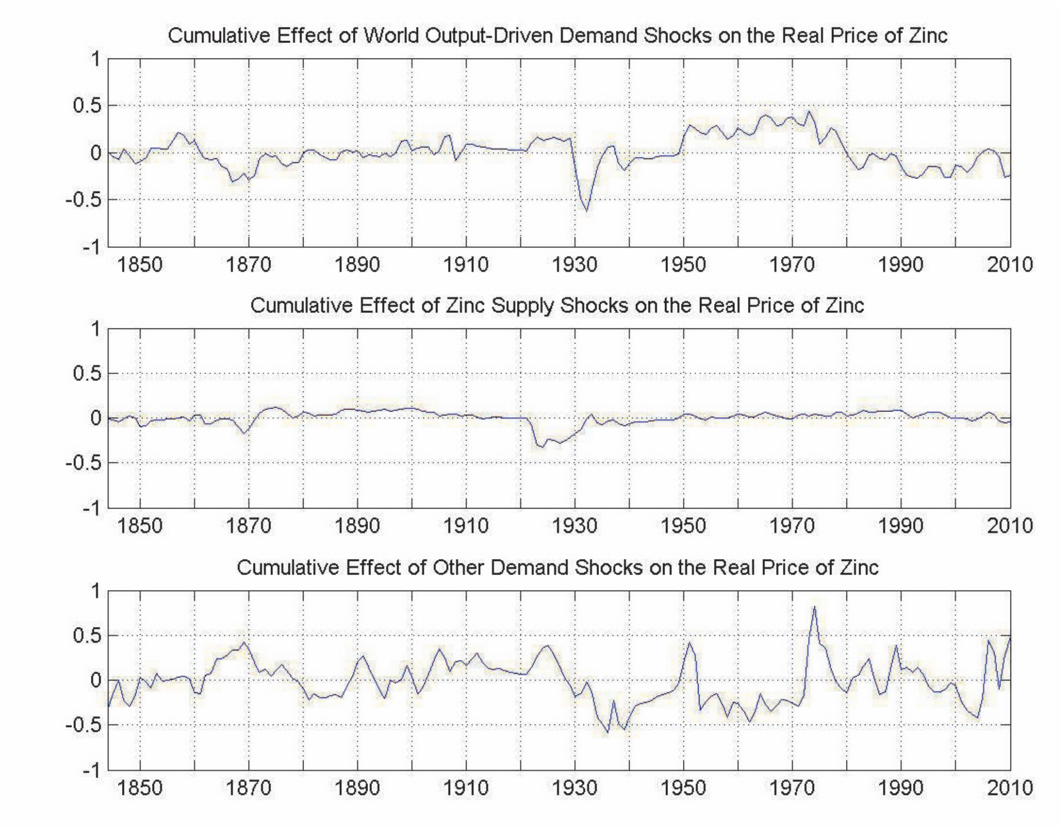
In the inter-war period, prices began by falling, then rose to a peak in the mid-1920s, slumped sharply during the Great Depression and did not recover from this low level until the end of the Second World War. My analysis shows the peak in the mid-1920s to be the result of positive "world output-driven 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 technique of smelting which made the zinc production from complex sulphide ores possible (Gupta 1982). These new techniques increased production especially in non-European areas such as Canada, Australia, Mexico, Rhodesia, and Indochina (Gupta 1982). As a result the production of flotation concentrate in the U.S. for example increase from 34,000 tons in 1921 to 500,000 tons in 1928 (Jolly 1997, 39).

The new competition from outside Europe triggered the formation of the European zinc cartel in 1928 but which was dissolved in 1929 due to disparate interests of its members (Jolly 1997; Gupta 1982). The Great Depression caused a major negative "world output-driven demand shock" in 1930 and send prices down. As a reaction, the European zinc cartel was revived and imposed a 45 percent cutback of production in 1931 which was raised to 55 percent in the following year (Jolly 1997). This explains the negative "supply shocks" during these two years. However, the cartel dissolved in 1934 as some participants cheated on their production and sales. Problems with the treatment of stocks, which started to be released on the market as "other demand shocks" show, were not solved (Jolly 1997; Gupta 1982). Several attempts to renew the cartel failed until a cartel called the International Sheet Zinc Cartel was founded at the end of the 1930s. It had a short impact on the market as the "other demand shocks" suggest but was dissolved by the start of World War II (Jolly 1997).

The high price level from the end World War II until the beginning of the 1970s was mainly driven by upwards pressure due to strong "world output-driven demand shocks" fueled by post-war reconstruction and the following industrial expansion in South-Korea and Japan. After World War II the U.S. enacted the Strategic and Critical Minerals Stock Piling Act which led to heavy stockpiling, visible in the sharp rise of accumulated "other demand shocks" and driving up prices enormously (Gupta 1982, 32). The following years were characterized by price controls and sales and purchases into the government stockpile in the U.S.. This economic policy strongly influenced the price in the rest of the world and had a rather destabilizing effect (Gupta 1982, 32). It is also visible ithe "other demand shocks". Furthermore, a new informal cartel was founded in 1964, known as the "Zinc Club" (Jolly 1997, 117). Its members, mainly European, Canadian, and Australian zinc companies aimed at supporting the newly introduced European Producer Price and to restrain the influence of the London Metal Exchange (Jolly 1997). They used inventories as a tool to set the European Producer Price (Jolly 1997).

At the beginning of the 1970s the zinc price increased dramatically. My analysis shows that

Figure 13: Historical decomposition of the real price of zinc



this was mainly driven by "other demand shocks". The U.S. government imposed a stabilization program in 1971 which fixed prices at a low level (Jolly 1997). After lifting the fixed price in 1973, both the U.S. producers and the "Zinc Club" increased their prices sharply by more than 225 percent (Gupta 1982, 30). As producers withhold stocks, visible in the strong accumulated response of the "other demand shocks", the price of the London Metal Exchange also increased drastically. In 1974 the recession had a strong negative shock on the price and producers were not able to support prices anymore such that prices dropped again (Gupta 1982). The governments of the U.S., Japan, and France helped zinc companies to reduce inventories in these times of a low zinc price by increasing government stocks in 1975 and 1976 (Gupta 1982). After investigations of the U.S. department of Justice, the informal "Zinc Club" collapsed in 1976 (Jolly 1997).

In the 1980s the zinc price reached peaks in the middle of the 1980s and at the end of the 1980s. Both are explainable by a combination of positive "world output-driven demand shocks" due to economic expansions of the world economcy (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 the zinc price over 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 Asian Crisis later on. The price increase at the beginning of the 2000s was fueled by positive “world output-driven demand shocks” until the Great Recession starting in late 2007 caused strongest negative “world output-driven demand shocks”. However, strong positive “other demand shocks” partly compensated for these negative shocks. They reflect a strong change in warehouse inventories of the London Metal Exchange and the Shanghai Futures Exchange, which have increased eightfold and sixfold in the period from 2007 to 2010 (International Lead and Zinc Study Group 2011). Interestingly data on inventories at consumers and producers have not increased over the time period (International Lead and Zinc Study Group 2011), which points to the role of institutional investors in buying 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 in recent time as an interpretation of the “other demand shock”.

5.5 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 trendless 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.

Table 1: Estimated coefficients of the linear trends

	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

6 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 for my baseline specification.

In order to check the robustness of the results over that of an alternative identification, I use Kilian’s identification scheme, which is based on short-run restrictions. I postulate a vertical short-run supply shape 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 also robust regarding alternative price data. Table 25 illustrates the empirical results obtained from using the producer price index instead of the consumer price index for disinflation.

Employing New York prices instead of London based prices (see Table 26) 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 subperiods. 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 24).

7 The case of crude oil

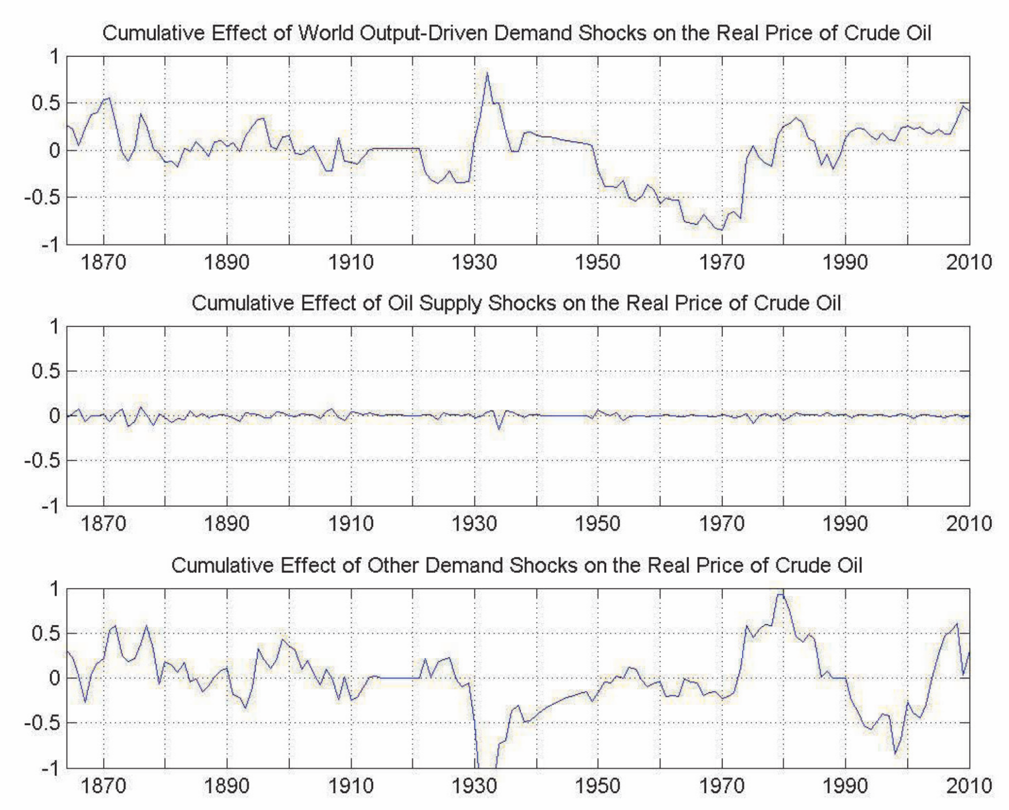
While the empirical results are quite robust for the four mineral commodities examined above, the results for the crude oil market are less compelling due to structural breaks in the time series. As a comparison, I present the empirical results in the following. The evolution of the variables is presented 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 Appenxid 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 behaviour is the still unsettled issue of causality in the relationship between the oil price and economic growth (see, e.g., Ozturk (2010) for an overview). 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.

The historical decomposition in Figure 14 reveals again the problem with 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.

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



The results for crude oil are not robust with respect to different subperiods due to the familiar structural changes in the oil market (see Kilian / Vigfusson 2011; Dvir / Rogoff 2010; Hamilton 2011). Results for the subperiods from 1900 to 2010 and from 1925 to 2010, which are presented in Table 24 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.

8 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 from 1840 to 2010. 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 hereby 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 controling for changes in inventories or the resource intensity of the economy would shed further light on the sources of these shocks.

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Appendices

Appendix 1 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 terms, notably 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

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

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

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

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 (2008) 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 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 the Federal Institute for Geosciences and Natural Resources)
	1929-1959	mt	Schmitz 1979, pp. 213-25	Refined production; according to the Federal Institute for Geosciences and Natural Resource the data includes both primary and secondary sources. This is also the case 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 - including production on toll in the reporting country regardless of the type of source material, i.e. whether 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.
Tin	1821-1883	mt	Neumann 1904, p. 251-3	
	1884-2010	mt	BGR, 2012	Primary tin production (smelter)
Zinc	1850-1879	mt	Schmitz 1979, p. 160-6	Mine production
	1880-1888	mt	Metallgesellschaft 1898, 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 including production on toll in the reporting country regardless of the type of source material, i.e. whether ores, concentrates, residues, slag, or scrap. Remelted zinc and zinc dust are excluded.
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	1771-1976	£/mt	Schmitz 1979, p. 268-72	1771-1779: Cornish copper standard; 1780-1879: 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; 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-$/mt	BGR, 2011	Grade A, cash, in LME warehouse
	New York	1850-1976	US-$/mt	Schmitz 1979, p. 268-72	1850-1899: Lake copper (fire-refined) New York; 1900-1976: electrolytic wirebars; Sep 1967-Apr 1968: US copper producer strike, so 1967 is the average of Jan-June and 1968 is the average of May-Dec.
	New York	1977-2010	US-$/mt	U.S. Geological Survey 2011a	U.S. Producer Price
Lead	London	1771-1976	£/mt	Schmitz 1979, p. 226-37	1771-1886: English pig lead, mostly prices in provincial markets pre-1850, then mainly London prices; 1887-1945: good soft pig lead; 1946-1976: refined pig, min. 99.97% metal content; 1914: average Jan-July and Nov-Dec only; 1940-Sept 1952: fixed selling price, Ministry of Supply
	London	1977-2010	US-$/mt	BGR, 2011	min. 99.97 %, LME, cash, in LME Lagerhaus
	New York	1812-1976	US-$/mt	Schmitz 1979, p. 274-78	1812-1879: pig lead, New York; 1880-1976: common grade lead, min. 99.73%
	New York	1977-2010	US-$/mt	U.S. Geological Survey 2011a	Domestic refined lead
Tin	London	1750-1976	£/mt	Schmitz 1979, p. 240-1	1750-1837: common refined tin, Cornwall; 1838-1872: standard tin; 1873-1976: standard tin, min. 99.75% cont.; 1914: Average price of Jan-July and Oct-Dec only; 1942-1949: controlled price, Ministry of Supply
	London	1977-1978	US-$/mt	U.S. Bureau of Mines 1980, p. 915	
	London	1979-2010	US-$/mt	BGR, 2011	Min. 99.85%, LME, cash, noon of tin in blocks and pigs from the U.K.
	New York	1851-1855	US-$/mt		Filled with linear trend

	New York	1856-1962	US-$/mt	Secretary of the Treasury 1864, p. 46-8	Computed from quantities and values of imports of tin in blocks and pigs
	New York	1863	US-$/mt	House of Commons 1866, p. 358	Computed from quantities and values of imports of tin in blocks and pigs
	New York	1864-1865	US-$/mt	House of Commons 1868, p. 378	Computed from quantities and values of imports of tin in blocks and pigs
	New York	1866-1869	US-$/mt		Filled with linear trend
	New York	1977-2011	US-$/mt	U.S. Geological Survey 2011a	Domestic refined tin; 2004: New York composite price.
Zinc	London	1823-1976	£/mt	Schmitz 1979, p. 299-303	1823-1951: Ordinary brands zinc, London market; 1940-1944: controlled price, U.K Ministry of Supply; 1952-1976: virgin zinc min. 98%, London market
	London	1977-1978	US-$/mt	U.S. Bureau of Mines 1980, p. 981	Prime Western grade, London
	London	1979-2010	US-$/mt	BGR, 2011	Special high grade, min. 99.995%, cash, LME warehouse
	New York	1853	US-$/mt	Schmitz 1979, p. 300-3	Prime Western Spelter, New York
	New York	1859, 1860	US-$/mt	House of Commons 1862	Import price of zinc in blocks and sheets
	New York	1863	US-$/mt	House of Commons 1866	Import price of zinc in blocks and sheets
	New York	1864-1865	US-$/mt	House of Commons 1868	Import price of zinc in blocks and sheets
	New York	1872-1874	US-$/mt	U.S. Bureau of Mines 1883	Import price of zinc in blocks or pigs
	New York	1875-1976	US-$/t	Schmitz 1979, p. 300-3	1875-1899: Prime Western Spelter, New York; 1900-1976: Prime Western Spelter, Saint Louis
	New York	1977-2010	US-$/mt	BGR, 2011	1977-2001: High-grade; 2002-2010: Special high grade
Crude Oil	US/UK	1861-2010	US-$/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
British £- US-$	1791-2010	US-$ per £	Officer 2011

Table 4: Data sources for the exchange rates.

Index	Country	Time	Unit	Source	Notes
PPI	U.K.	1840-1913	2005=100	Mitchell 1988, p. 722-4	
	U.K.	1914-1959	2005=100	Mitchell 1988, p. 725-7	
	U.K.	1960-2010	2005=100	World Bank 2012	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.	1800-2010	Jan 1974=100	U.K. Office of Statistics 2011	Composite Price Index
	U.S.	1774-2008	1982-1984=100	Officer and Williamson 2011	

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 Figures

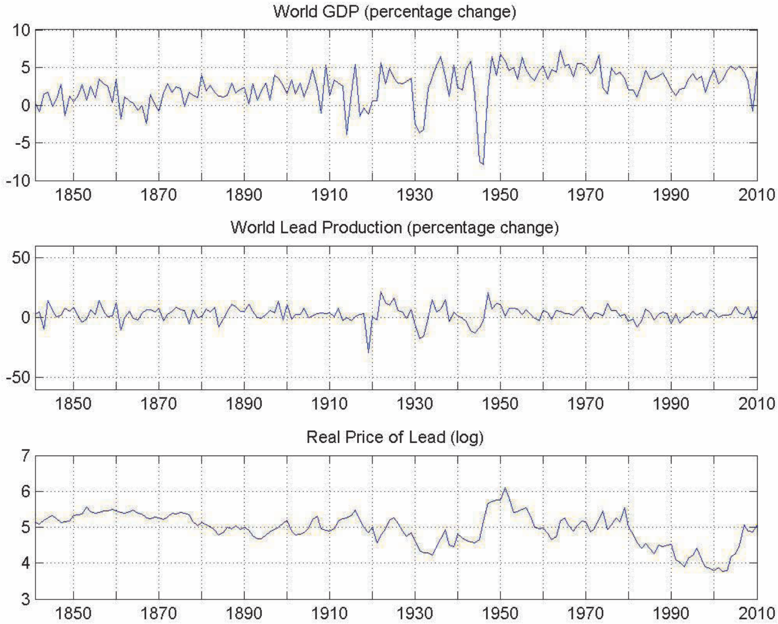


Figure 15: Historical evolution of world GDP, world lead production, and the real price of lead from 1841 to 2010.

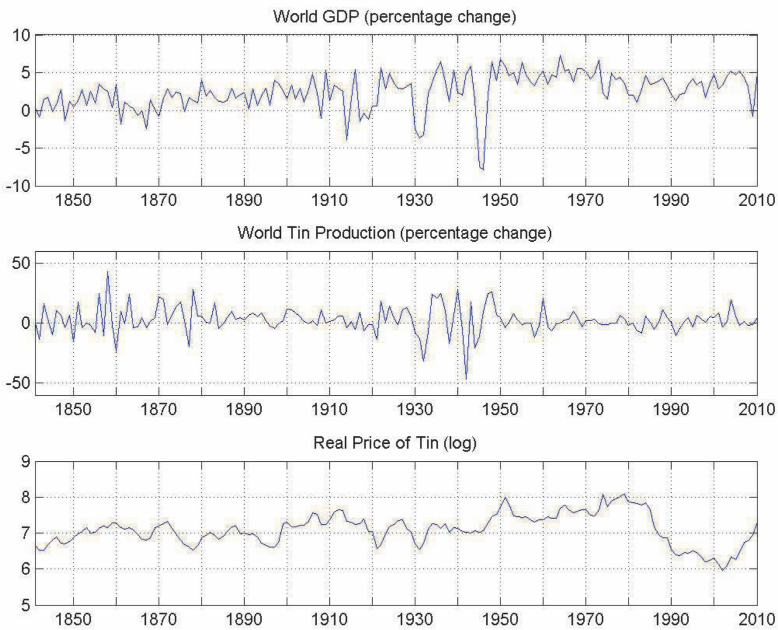


Figure 16: Historical evolution of world GDP, world tin production, and the real price of tin from 1841 to 2010.

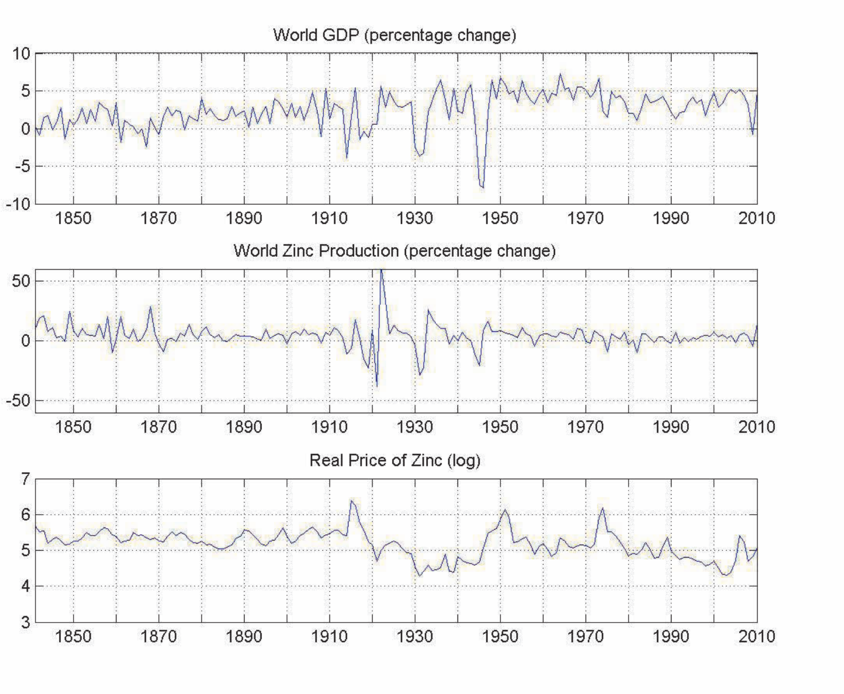


Figure 17: Historical evolution of world GDP, world zinc production, and the real price of zinc from 1841 to 2010.

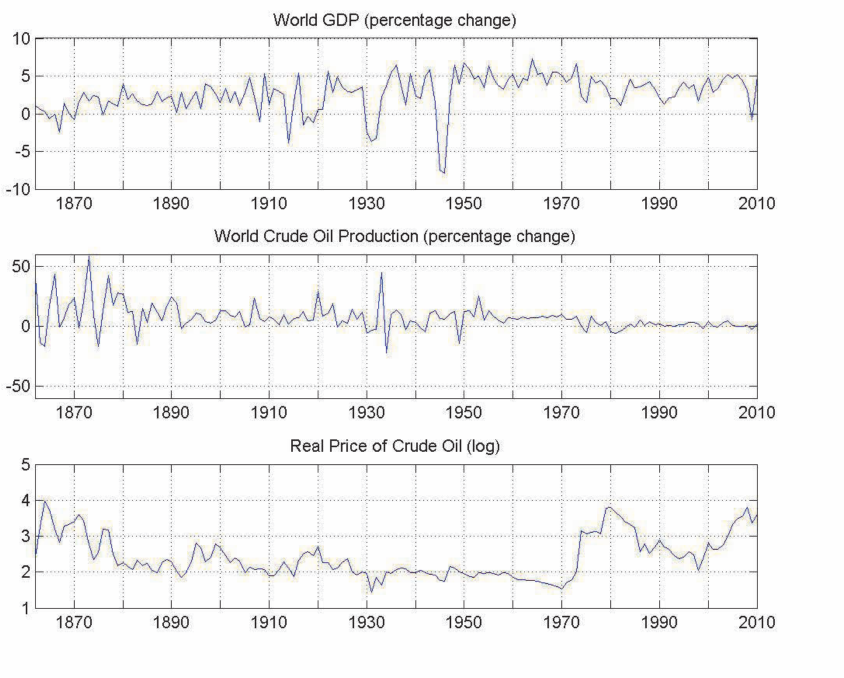


Figure 18: Historical evolution of world GDP, world crude oil production, and the real price of oil from 1862 to 2010.

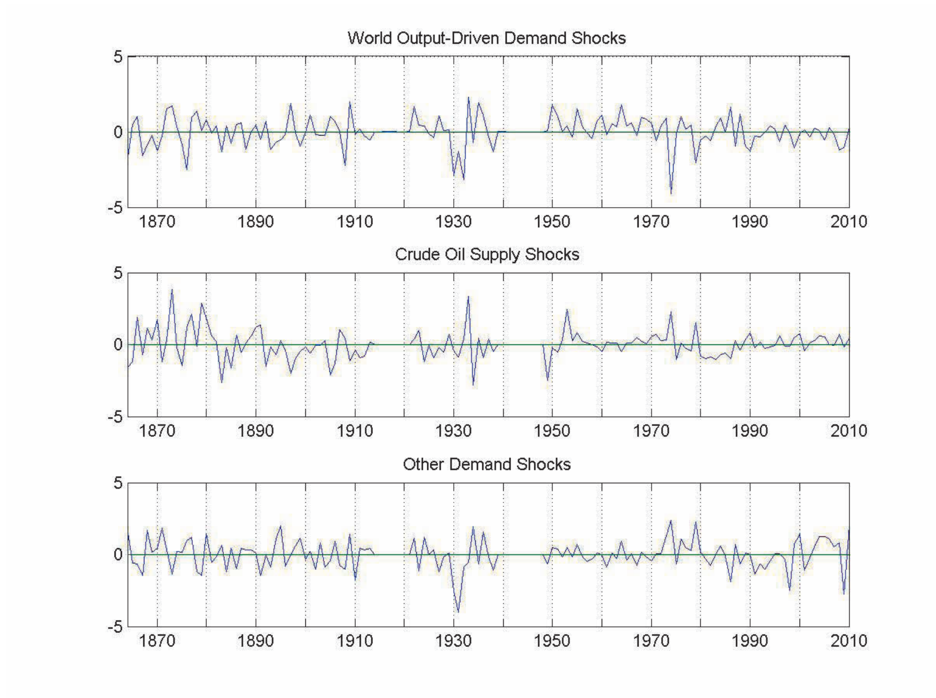
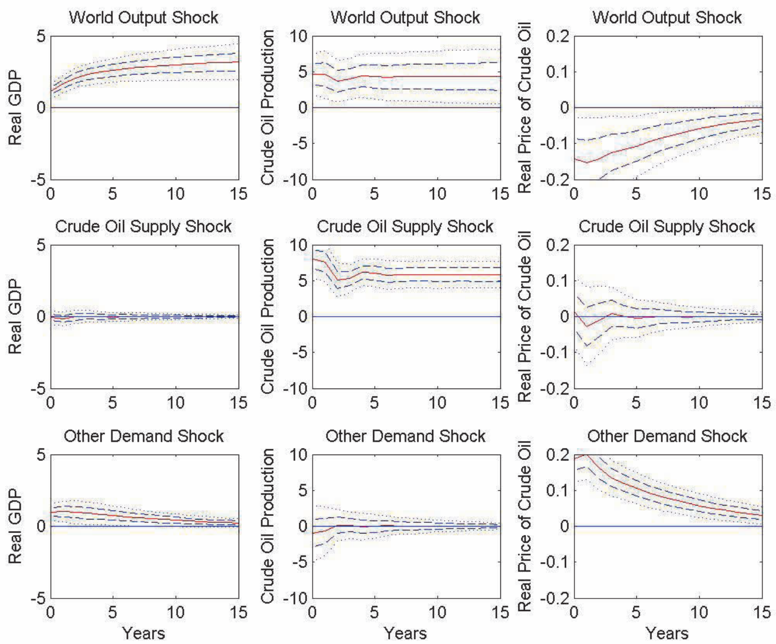


Figure 19: Historical evolution of the structural shocks for crude oil.



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.

Appendix 4 Regression results

Indep. variable	Coefficient	t-statistic	t-probability
Dependent variable: World GDP (percentage share)			
World GDP lag1	0.375	3.964	0.000
World GDP lag2	0.353	3.281	0.001
World GDP lag3	0.149	1.603	0.111
World GDP lag4	-0.196	-2.340	0.021
Production lag1	-0.025	-1.547	0.124
Production lag2	-0.008	-0.518	0.605
Production lag3	-0.035	-2.345	0.021
Production lag4	-0.003	-0.206	0.837
Price lag1	-1.539	-1.661	0.099
Price lag2	-0.544	-0.436	0.663
Price lag3	0.206	0.170	0.865
Price lag4	1.790	2.122	0.036
Constant	1.267	0.344	0.731
Trend	0.005	0.660	0.510
Dependent variable: Copper production (percentage share)			
World GDP lag1	1.950	4.366	0.000
World GDP lag2	1.706	3.355	0.001
World GDP lag3	0.810	1.848	0.067
World GDP lag4	-0.258	-0.650	0.517
Production lag1	-0.287	-3.701	0.000
Production lag2	-0.258	-3.493	0.001
Production lag3	-0.374	-5.245	0.000
Production lag4	-0.245	-3.333	0.001
Price lag1	-13.522	-3.088	0.002
Price lag2	-2.990	-0.507	0.613
Price lag3	3.053	0.533	0.595
Price lag4	4.787	1.200	0.232
Constant	68.142	3.916	0.000
Trend	-0.184	-5.172	0.000
Dependent variable: Price of copper (logs)			
World GDP lag1	0.031	3.024	0.003
World GDP lag2	0.009	0.756	0.451
World GDP lag3	0.011	1.044	0.299
World GDP lag4	-0.002	-0.171	0.865
Production lag1	-0.004	-2.273	0.025
Production lag2	-0.002	-1.122	0.264
Production lag3	-0.001	-0.597	0.552
Production lag4	-0.001	-0.604	0.547
Price lag1	0.850	8.366	0.000
Price lag2	-0.164	-1.198	0.233
Price lag3	0.063	0.474	0.636
Price lag4	0.086	0.929	0.355
Constant	1.130	2.801	0.006
Trend	-0.002	-2.811	0.006

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
	(6.383)	(0.917)	(0.185)
Production	1.298	4.805	5.488
	(1.602)	(4.295)	(3.930)
Price	0.102	-0.091	0.105
	(1.859)	(-2.990)	(5.100)

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 standard errors are 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	4.002	0	0
	(2.623)	—	—
Production	1.394	5.496	0
	(0.714)	(3.919)	—
Price	1.744	-0.818	0.633
	(1.785)	(-2.378)	(3.958)

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 standard errors are 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 share)			
World GDP lag1	0.265	2.762	0.007
World GDP lag2	0.130	1.289	0.199
Production lag1	0.019	0.665	0.507
Production lag2	0.017	0.649	0.517
Price lag1	-0.466	-0.500	0.618
Price lag2	0.341	0.405	0.686
Constant	1.173	0.522	0.602
Trend	0.011	2.229	0.027
Dependent variable: Lead production (percentage share)			
World GDP lag1	0.958	3.102	0.002
World GDP lag2	-0.457	-1.409	0.161
Production lag1	0.039	0.426	0.670
Production lag2	0.031	0.363	0.717
Price lag1	4.933	1.645	0.102
Price lag2	-4.592	-1.695	0.092
Constant	1.321	0.183	0.855
Trend	-0.013	-0.814	0.417
Dependent variable: Price of lead (logs)			
World GDP lag1	0.031	3.257	0.001
World GDP lag2	-0.021	-2.053	0.042
Production lag1	0.001	0.303	0.763
Production lag2	0.004	1.422	0.157
Price lag1	0.888	9.597	0.000
Price lag2	-0.040	-0.474	0.636
Constant	0.782	3.506	0.001
Trend	-0.001	-1.871	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	0.127
	(7.052)	(-0.819)	(0.397)
Production	2.664	4.604	-0.344
	(3.192)	(6.399)	(-0.324)
Price	0.060	0.008	0.153
	(1.700)	(0.247)	(6.149)

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 standard errors are 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
	(0.620)	—	—
Production	4.666	5.028	0
	(1.584)	(0.834)	—
Price	0.732	0.209	1.010
	(0.365)	(0.241)	(0.304)

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 standard errors are 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 share)			
World GDP lag1	0.263	2.840	0.005
World GDP lag2	0.159	1.612	0.109
World GDP lag3	-0.020	-0.249	0.803
Production lag1	0.002	0.128	0.898
Production lag2	-0.008	-0.523	0.602
Production lag3	-0.026	-1.817	0.071
Price lag1	0.428	0.424	0.672
Price lag2	0.533	0.352	0.726
Price lag3	-0.705	-0.736	0.463
Constant	-1.056	-0.442	0.659
Trend	0.011	2.868	0.005
Dependent variable: Tin production (percentage share)			
World GDP lag1	1.664	3.278	0.001
World GDP lag2	0.418	0.773	0.441
World GDP lag3	-1.098	-2.527	0.013
Production lag1	-0.164	-1.961	0.052
Production lag2	-0.141	-1.766	0.080
Production lag3	-0.124	-1.583	0.116
Price lag1	-5.369	-0.971	0.333
Price lag2	15.807	1.906	0.059
Price lag3	-12.616	-2.406	0.017
Constant	20.780	1.588	0.115
Trend	-0.046	-2.115	0.036
Dependent variable: Price of tin (logs)			
World GDP lag1	0.007	0.866	0.388
World GDP lag2	-0.017	-1.930	0.056
World GDP lag3	0.001	0.140	0.889
Production lag1	-0.001	-0.727	0.468
Production lag2	-0.001	-0.733	0.465
Production lag3	-0.001	-0.586	0.559
Price lag1	1.262	14.265	0.000
Price lag2	-0.421	-3.174	0.002
Price lag3	0.098	1.166	0.246
Constant	0.466	2.225	0.028
Trend	0.000	0.316	0.753

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	1.507	0.532	-0.390
	(5.824)	(1.469)	(-0.911)
Production	0.376	8.364	3.322
	(0.317)	(6.501)	(1.294)
Price	0.097	-0.050	0.094
	(2.219)	(-1.444)	(3.575)

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 standard errors are 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	2.981	0	0
	(3.975)	—	—
Production	0.575	7.589	0
	(0.258)	(4.231)	—
Price	1.141	-1.139	1.525
	(1.137)	(-1.494)	(2.727)

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 standard errors are 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 share)			
World GDP lag1	0.333	3.432	0.001
World GDP lag2	0.151	1.497	0.137
World GDP lag3	-0.017	-0.209	0.835
Production lag1	-0.017	-1.029	0.305
Production lag2	0.024	1.420	0.158
Production lag3	-0.028	-1.776	0.078
Price lag1	0.814	0.964	0.337
Price lag2	-1.911	-1.654	0.100
Price lag3	1.247	1.511	0.133
Constant	-0.115	-0.039	0.969
Trend	0.010	2.067	0.041
Dependent variable: Zinc production (percentage share)			
World GDP lag1	1.285	2.629	0.010
World GDP lag2	-0.077	-0.151	0.880
World GDP lag3	-1.052	-2.532	0.012
Production lag1	-0.085	-0.100	0.319
Production lag2	-0.104	-1.245	0.215
Production lag3	-0.113	-1.455	0.148
Price lag1	-2.860	-0.673	0.502
Price lag2	-2.627	-0.451	0.652
Price lag3	4.647	1.118	0.266
Constant	13.170	0.876	0.383
Trend	-0.036	-1.412	0.160
Dependent variable: Price of zinc (logs)			
World GDP lag1	0.025	2.415	0.017
World GDP lag2	-0.001	-0.098	0.922
World GDP lag3	-0.008	-0.878	0.382
Production lag1	-0.005	-2.555	0.012
Production lag2	0.001	0.472	0.637
Production lag3	-0.001	-0.596	0.552
Price lag1	1.064	11.846	0.000
Price lag2	-0.563	-4.581	0.000
Price lag3	0.337	3.834	0.000
Constant	0.890	2.799	0.006
Trend	-0.001	-1.777	0.078

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	1.622	0.163	-0.142
	(7.054)	(0.860)	(-0.390)
Production	3.447	7.449	0.800
	(3.212)	(4.847)	(0.483)
Price	0.080	-0.014	0.154
	(1.820)	(-0.394)	(5.597)

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 standard errors are 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	3.149	0	0
	(3.976)	—	—
Production	2.555	5.888	0
	(1.801)	(5.040)	—
Price	0.731	-0.256	0.952
	(1.749)	(-1.071)	(3.056)

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 standard errors are in brackets. Maximum likelihood estimation, scoring Aagorithm (see Amisano and Giannini (1992)).

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

	Coefficient	**t-statistic**	**t-probability**
Dependent Variable: World GDP (percentage share)			
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 share)			
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 standard errors are 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 standard errors are 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 5 Sensitivity analysis

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	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	46	12	42	38	21	40	33	23	43
Zinc	LR	1841-2010	London	CPI	3	21	1	79	30	4	66	32	4	64
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	61
Tin	SR	1841-2010	London	CPI	3	14	0	85	11	3	86	8	4	88
Zinc	SR	1841-2010	London	CPI	3	9	4	86	21	2	77	22	2	76
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	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	4	50
Tin	LR	1900-2010	London	CPI	3	49	29	22	36	41	22	30	43	27
Zinc	LR	1900-2010	London	CPI	3	39	9	52	49	12	39	50	12	38
Cr. Oil	LR	1900-2010	Int.	CPI	2	49	33	18	43	34	23	43	34	23
Copper	LR	1925-2010	London	CPI	4	38	5	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	67	22	11	52	33	15	33	34	22
Zinc	LR	1925-2010	London	CPI	3	35	4	61	53	12	36	57	11	32
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 24: 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	13	3	84	13	7	80	12	8	81
Tin	LR	1841-2010	London	PPI	3	33	16	51	24	28	48	20	30	50
Zinc	LR	1841-2010	London	PPI	3	18	4	77	17	4	79	18	4	77
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 25: 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 26: Forecast error variance decomposition for the baseline specification using New York instead of London prices.

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