A Dynamic Analysis of Collusive Action: The Case of the World Copper Market, 1882-2016

Rausser, Gordon and Stuermer, Martin

University of California, Berkeley, Federal Reserve Bank of Dallas

December 2020

A Dynamic Analysis of Collusive Action: The Case of the World Copper Market, 1882-2016*

Gordon Rausser† and Martin Stuermer‡

November 2020

Abstract

We advance a new framework for investigating the dynamic effects of collusion. In contrast to the standard reduced-form workhorse model, a structural vector autoregressive model with sign restrictions allows us to endogenize cartel action and to distinguish unexpected market manipulations from other types of shocks. Utilizing a newly constructed monthly data set for the copper market from 1882 to 2016, we find that cartel action shocks have strong effects on price and output during collusive periods. More notably, these shocks have lessening, yet quite persistent impacts over the subsequent unwinding periods in which output damages dominate price damages.

JEL classification: K2, L1, Q2, N5

Keywords: Collusion, market distortions, economic damages, structural time series, commodity markets

*We are grateful for comments from Christiane Baumeister, Alexander Chudik, Nathan Delaney, Jim Hamilton, Lutz Kilian, Karel Mertens, Xiaqing Zhou, and participants of the Annual Meeting of the American Economics Association in Boston, the Annual Meeting of the Canadian Economic Association in Toronto, the Annual Meeting of the Association of Environmental and Resource Economics in San Diego, the Summer Meeting of the European Economic Association as well as seminars at Rice University and the Federal Reserve Bank of Dallas. We thank Grant Strickler, Camila Holm, Anna Eckert, Sean Howard and Leopold Biardeau for excellent research assistants. An earlier version of this paper was distributed with the title "Collusion in the World Copper Market: A Long-Run Perspective." An online appendix is available at https://sites.google.com/site/mstuermer1/.

†University of California, Berkeley, Email: rausser@berkeley.edu.

‡Federal Reserve Bank of Dallas, Email: martin.stuermer@dal.frb.org. The views in this paper are those of the authors and do not necessarily reflect the views of the Federal Reserve Bank of Dallas or the Federal Reserve System.

1 Introduction

This paper measures the dynamic market effects of collusion in the global copper market from 1882 to 2016. In contrast to much of the literature that uses the “workhorse” static reduced-form pricing model, we are to our knowledge the first to advance a dynamic structural model that accounts for the endogeneity of cartel action.[1] We distinguish cartel action shocks from other shocks, including copper supply shocks, demand shocks due to the global business cycle, as well as copper market-specific demand shocks. As a result, we are able to quantify price and output damages both during the cartel action periods but also during the subsequent “unwinding” periods.

We build on a structural vector auto-regressive model with sign restrictions to set-identify collusive action shocks.[2] Our identification rests on the simple idea that cartel action is more likely to emerge and can be sustained when prices decline and do not increase. A shock that we interpret as an output restriction shock is assumed to have a negative effect on the cartel's output and the world's output, which drives up the real price. In contrast, we assume that a non-cartel supply shock also has a negative effect on world copper output, which leads to increased prices and exhibits a positive effect on the cartel's output. The idea is that as prices increase, the cartel has less incentives to restrict output and instead increases production ceteris paribus. As prices increase, each

[1]Our paper is at the intersection of industrial organization and time series econometrics. Data limitations (e.g. entry and exit of firms) do not allow us to use a structural industrial organization model.

[2]Faust (1998),Canova and De Nicolo (2002) and Uhlig (2005) have pioneered this model, which has become common in applied macroeconomics literature.

colluding firm has a strong incentive to cease restricting output and cheat (Marshall and Marx, 2012, p. 7).

Similarly, a positive collusive stock manipulation shock is based on the reasonable proposition that it positively affects the real price, output and the cartel's inventories. This type of shock captures unexpected changes in cartels' copper inventory to manipulate prices. In contrast, a positive copper market-specific demand shock is expected to have a positive effect on price and output, but a negative effect on the cartel's stock accumulations because the higher price discourages cartel action.

We apply the econometric model to a new monthly data set on global copper output, prices, and cartel actions from 1882 to 2016. We also constructed a monthly global activity index based on ocean shipping freight rates. This data set allows us to examine the effects of subsequent periods of cartel action and to track their long-run effects.

We derive three key results: First, output restrictions damage consumers, while collusive stock manipulations benefit consumers in the long run. Both lead to higher prices during the collusive action period. However, stock manipulations lead to persistently depressed prices in the unwinding periods more than offsetting the damage during the action periods. Output restriction have only a small and ambiguous negative effect during the unwinding periods. Second, output damage is more important than price damage. The main reason is that collusive action has persistent effects on output beyond the collusive action period. This could be driven by a negative impact on exploration and investment during the cartel action periods. Finally, collusive output restrictions lower the future output path over the long run, while collusive stock manipulations leads to higher output.

These results suggest that output damage is more important than previously thought in the literature due to its persistent effects. It should be a consideration in antitrust litigation. Currently, courts in the U.S., the European Union and elsewhere focus only on price damage.

In the following section, we present the relevant literature in section 2; in section 3, we show the geographic and product scope of the copper market, in section 5 we introduce the data set and in section 4 we cover the episodes of alleged collusion. We lay out the dynamic structural model and the computation of the but-for price and output, as well as the damages that take place both with regard to price as well as output levels in section 6. In section 7, we present and discuss our empirical results. Section 8 provides results from a sensitivity analysis. Finally, section 9 is the conclusion.

2 Review of the Relevant Literature

The literature on the market impacts of collusion largely focuses on reduced form pricing analysis. The workhorse in antitrust litigation matters is reduced form regressions. Baker and Rubinfeld (1999, p. 392) note that "the price effect of the alleged conspiracy is measured by the coefficient on a dummy variable that takes on the value of one during the period (or in the markets) in which the conspiracy is in operation." Recognizing the heterogeneity that exists for individual transactions between sellers and buyers, Hartman and Doane (1987, p. 352) propose a reduced form pricing hedonic approach that is capable of identifying and measuring "...the commonality in a group of apparently heterogeneous products, services, or individuals." Along similar lines, Brander and Ross (2006, p. 342) advanced before and after comparisons, simply comparing "...the price before the price-fixing conspiracy with the price that occurred after the price-fixing conspiracy became active." The before period is typically advanced as the control period in which non-collusive prices are presumed to be generated. Other empirical studies have used the post-collusive period as a benchmark, other product markets, and in some instances other geographic markets which cover the same product or same service's scope. (Connor and Bolotova, 2006)

Prior empirical studies revealed that post-collusive prices likely have a different mean and variance than the pre-collusive prices. Bolotova et al. (2008) study this in the context of the citric acid conspiracy (1991-1995) and the lysine conspiracy (1992-1995). For citric acid, the mean post-collusive price is 12% higher than the pre-collusive price. The post-collusive standard deviation of citric acid is 55% lower than the standard deviation of the pre-collusive price. With regard to lysine, pre-collusive and post-collusive prices are similar but the post-collusive price standard deviation is 41% lower. The authors conclude that prices may or may not return to the pre-collusive price level and consequently, using the post-collusive price as a proxy for the competitive price, may underestimate the consequences of collusive actions. In the Vitamins Antitrust Litigation, Bernheim (2002) reaches a similar conclusion to the citric acid and lysine empirical analysis, finding that prices gradually returned to pre-collusive levels over a 12 month period.

There are several theoretical models that focus on tacit collusion under imperfect public information. In the seminal paper by Green and Porter (1984), the model of perfect collusion is impossible because of imperfect information. They identify several alternative equilibria, including that price wars (Cournot episodes) are essential in sustaining collusion. A recent theoretical piece by Bos and Harrington (2010) provides insights on the distribution of cartel members. They presume a direct relationship between output and capacity of each cartel member. The distributional aspects make clear that larger firms have more incentive to join the cartel than smaller firms. The policy insight from their theoretical formulation is to restrict mergers that lie between the small firms and the large firms, allowing those merged entities to act as larger firms would in being members of the formation of cartels. Specifically, a merger between two moderate-sized firms may significantly expand the size and profitability of a potential cartel.

Harrington (2004) presents the theoretical foundations for strategic collusion in the post-cartel period centered upon U.S. antitrust policy. The model predicts that the post-collusive price is higher when firms assign more weight to damages, the cartel has a longer duration and the industry is more concentrated. The author conducts an empirical analysis of the graphite electrodes cartel (1992-1997) and finds that two years after the collusion presumably terminated, the price was still 20% above its pre-collusion level. Erutku (2012) implements the Harrington (2004) formulation in the context of the retail gasoline collusion in the province of Quebec (Canada). The author finds that the post-cartel price actually increases (relative to the pre-cartel period) upon the filing of legal action, but then decreases as the antitrust case is slowly unwound.

Two surveys provide additional empirical results consistent with those outlined above. In a meta-analysis, Connor and Bolotova (2006) find that the use of a post period benchmark underestimates overcharges when compared to other benchmarks (geographic or product) by approximately 11% because collusive distortions persist after the disbanding of the cartel. In a second survey, Levenstein and Suslow (2006) examine several cases of known cartels focusing on duration, causes for cartel breakdown, and the degree of impact. Regarding the impact on prices post cartel dissolution, the paper notes that there are studies that show manipulated price elevations even following antitrust prosecution.[3]

Several studies that have examined market power in the copper industry inform the specifications of our model. For example, Agostini (2006) examines the hypothesis of a two-price system orchestrated by export quotas being implemented in the United States. This had the effect of eliminating some arbitrage opportunities and degree of market power by U.S. suppliers. In Luengo Morales (2015), there is strong evidence of market power and strategic behaviors among firms participating in the international copper industry. He computes an average Lerner index of 42 percent, which suggests a stronger degree of market power. Another model examining the International Copper Industry has been presented by Luengo (2019). He contradicts the results of Luengo Morales (2015) finding no evidence supporting collusive behavior among producers in copper industry. He

[3]There are a number of potential explanations for the collusive unwinding period, including long-term contracts delaying price adjustments (Bolotova et al., 2008), tacit strategies that allow some collusive influence to persist (De Roos, 2006), high market concentrations (Harrington, 2004), imprecise dates that signify the end of a collusive era (Bolotova et al., 2008), and cost structures that may reflect collusion inefficiencies (Bolotova et al., 2008).

suggests that the substitution effect of aluminum may be restricting any attempts to increase copper prices. He finds the Cournot equilibrium is the most likely outcome of the strategic interactions among copper suppliers. Guzmán (2018) investigates specifically the last of the alleged collusive periods in our sample, finding that the cartel mechanisms implemented was not cooperative and in effect, competitive, theorizing that the so-called "trigger price mechanisms" could be welfare-enhancing because of the reductions in price volatility without any changes in the average level of prices. In another study, Slade (2020) examines one of our alleged cartel periods (1887-89) that has been characterized as the Secretan Copper Cartel. She argues that the cartel was forced to acquire much inventory to maintain high prices, which was accomplished through direct purchases of the physical commodities in spot markets and sufficient amounts of future contracts. Ultimately, this cartel period came undone and inventory stocks found their way back onto the market, resulting in prices that collapsed to pre-1887-89 levels.

There have been a number of generic studies on market manipulation across various world commodity markets, perhaps the best comprehensive study available is Pindyck (1979). He specifies the market structures that are conducive to cartel behaviors. In a subsequent study, Slade (1989) also examines the structures that are conducive as well as those structures that undermine collusive conduct. She focuses on market arrangements for various commodities and the factors influencing price and cost stability. She finds that any byproducts generated from metal mining are often more sensitive than we would expect to the price of the primary commodity (e.g. silver vs copper).

These general commodity market examinations are followed by specific studies on the global oil market. Branger et al. (2020) find that higher monopoly profits in the oil industry attract investment in capital, which drives down marginal costs and stimulates long-term growth in the economy, expanding global real economic activity in the long run. Asker et al. (2019) focus on the implication of misallocation of production and any impacts that might arise in regards to total factor productivity within the oil industry and the entire economy over the period 1970-2014.

3 Geographic and Product Scope of Copper

3.1 Worldwide Geographic Scope of the London Metal Exchange

The copper price at the London Metal Exchange is well-recognized as an accurate representation of the supply and demand forces throughout the world. The exchange is still the principal market place that establishes prices (Schmitz, 1979; Slade, 1991; Wagenhals, 2012). There is ample evidence that copper trades within an integrated world market over most of the examined time period from 1882 to 2016 (see Klovland, 2005; O'Rourke and Williamson, 1994; Labys, 2008). This implies that price movements are approximately in accordance with the law of one price across space.

Price levels differed due to transportation costs or trade barriers in earlier periods, even though these two factors were relatively unimportant (see McNicol, 1975), particularly when compared to, for example, steel or coal markets. Of course, during the two World

Wars, the market temporarily halted due to price and supply controls (Backman and Fishman, 1941; Findlay and O'Rourke, 2007). During the so-called two-price-system from the end of the Second World War to 1978, there was the U.S. producer price and the London Metal Exchange price (McNicol, 1975; Slade, 1989, 1991).[4] However, arbitrage between the two systems kept the U.S. producer price roughly in line with the London price for the vast majority of the time (see Richard, 1978).

Unfortunately, historical cost data for the global copper market is sparse. As we could not come up with an annual or monthly time series, we cannot include such a variable is not included in the econometric analysis. However, Herfindahl (1959) suggests that the cost has stayed rather stable over the period based on his examination of the market from 1870 to 1957.[5]

3.2 Product Scope

Copper has maintained a track record of broad use (Radetzki, 2009). It is an input either in pure form or as an alloy to a broad variety of intermediate and manufacturing goods. Main industries using the metal are electronic products, construction, machinery and home appliances.

Copper can be substituted by aluminum, steel and plastic for certain applications. Empirical evidence of the magnitude and the statistical significance of any cross-price

[4]There was also the exchange determined copper price at COMEX in New York but which was relatively unimportant at the time.

[5]Stuermer and Schwerhoff (2015) provide a theoretical explanation for stable long run cost, namely that depletion of high grade deposits is off-set by technological change in resource extraction.

elasticities is weak or near zero for aluminum (Fisher et al., 1972; Richard, 1978) and plastic (Agostini, 2006). We are not aware of any quantitative study regarding steel. The irreversible character of substitution, which requires substantial capital investment by manufacturers, may help to explain these results (Richard, 1978). It is therefore a reasonable assumption that substitution of copper by other materials is not sufficiently impactful to undermine manipulation of copper prices over the short run.

Copper mining has several by-products with low relative value. The most important by-products in U.S. copper mines, namely gold, silver and molybdenum, were each only five percent or less of the total output value.[6] By-products vary by region such that price changes for individual by-products may not affect global copper output (Agostini, 2006).

Due to its geology, reserves of copper are primarily found in a narrow range of countries, thereby highly concentrating this market in terms of world production across countries. The main producing countries are Chile, the U.S., Zambia, and Peru.

Entry into the copper market is rather difficult. There are long lead times for opening and expanding mines due to exploration, high capital costs, infrastructure needs, the extensive removal of rock (Wellmer, 1992; Radetzki, 2008). Cartels tend to not face much competition from outsiders over the short-run.

[6]We source the output data for this exercise from Ayres et al. (2013) and prices from Stuermer and Schwerhoff (2015). The data refers to the year 1982.

4 Major Events of Collusion in the Copper Market

Over the course of the last two centuries there have been many attempts to cartelize the world copper market. Unfortunately, comparable and consistent historical data on many aspects of these cartels is not available. This is particularly true for the entry and exit of individual cartel members, cartel enforcement mechanisms and discipline issues. Section C in the appendix provides a detailed characterization of the eight treatment periods.

To assemble a monthly data set on periods of alleged collusion, we first assessed all of the narrative evidence from the literature and data sources, identifying 14 periods of potential collusion in the copper market. We excluded those periods, where we could find narrative evidence that cartels did not have a significant impact due to a small world market share (e.g. Lakes copper producers' selling pool 1870-1886), collusion was not successfully achieved (e.g. the attempts of an agreement between European and U.S. producers in 1895), or cartels had only a negligible effect according to narrative evidence (e.g. output restriction by several U.S. producers in 1908) Herfindahl (see 1959). Given those exclusions, we have nine treatment periods in our sample, but for one of these, price manipulations by large U.S. producers in 1912 and 1913, there is no information on the degree of output restrictions. Elliott et al. (1937, p. 399) characterizes this episode as only a modest essay in price manipulation. Hence, we are left with a total of eight treatment periods, which are recorded in Table 1, along with actions pursued by the alleged cartel.

Insert Table 1 about here.

The collusive action periods begin with the Secrétan Copper Syndicate (1887-1889) and evolve through different international cartel agreements and associations lasting from the end of the 19th century to the interwar period, and end with the Intergovernmental Council of Copper Exporting Countries (CIPEC), which existed from 1967 to 1988.

We distinguish between the official start and end dates of the cartels and that of alleged cartel action. We make this distinction because cartels are often formally in place for a long time, but they do not engage in cartel action over the entirety of their lifespan. For example, CIPEC served as a forum for discussion during most of its existence, but only took collusive action from late 1974 to 1976. Overall, there were cartels in place nominally during most of the sample period, except for the time period after 1990.

Most cartels were orchestrated by dominant firms. The only cartel involving governments was the Intergovernmental Council of Copper Exporting Countries, which imposed output restrictions from 1974 to 1976. The cartels in our sample differ in their legal status. Some were legal but acted in secret at first like the Secretan Copper Syndicate. Others were legal and operated openly. For example, the Copper Export Association was based on the Webb-Pomerene Act, which exempted certain exporters' associations from some antitrust regulations. Finally, some cartels were partially illegal, as U.S. firms faced antitrust regulations while some other international member firms did not (e.g. the International Copper Cartel).

Cartels in our sample used two main instruments to manipulate prices, namely output restrictions and stock accumulations. Output restrictions decrease copper production by either imposing production quotas or export quotas. Stock accumulations function through a centralized agency that purchases copper from the market or from cartel participants, and stockpiles copper until the right conditions arise for selling it.

5 Data Set: Prices, Output and Freight Rates

We collect monthly data for cartel actions, global copper output, prices and freight rates from January 1882 to December 2016.[7]

5.1 Cartel Action Variables

We collected data on the cartels' quantities of output for the majority of collusive action episodes from primary and secondary sources. Where this was not possible, we compute these quantities based on information about announced quotas and base years. The largest announced output restrictions were made in the 1920s and 1930s.

The data on cartels' stock holdings of copper are realized holdings during all examined periods. These stocks were held by a centralized institution or a designated firm, which made cheating by participants difficult and provides us with records of their stocks.

We transform the data such that it shows how world copper supply (more precisely the total quantity put on the market) would have changed as a percentage change due to the change in the respective cartel's output alone. We also compute the percent change in the cartel's copper stocks in relation to world copper output.

[7] We refrain from including more recent data at this point. Global copper output data is subject to revisions for several years.

There are two reasons for doing so: First, the level of world output has strongly increased over time, which changes the size of collusive actions relative to the size of the market. By our transformation, we can account for this. Second, we regress the variable on percentage change in total world output.

We normalize the variables so that an increase in stocks or a decline in output increases the price of copper. Figure 1 depicts the two cartel action variables and the other endogenous variables in our regression. Outside of the cartel action periods the two variables take on zero entries.

Insert Figure 1 about here.

5.2 Real Price Data

Spot price data for standard contracts at the London Metal Exchange come from the Metallgesellschaft AG, the American Metal Market Company, the U.S. Geological Survey and others (see online-appendix). We make sure that changes in contracts do not lead to jumps in the price series. We convert London prices in Pound Sterling to U.S. Dollar using exchange rates from the Federal Reserve Bank of St. Louis. We also collected New York price data for the sensitivity analysis. We deflate both price series before 1912 with the U.S. general price index from the National Bureau of Economic Research and afterward with the U.S. consumer price index from the U.S. Bureau of Labor Statistics.[8]. Detailed

[8]U.S. producer price data is only available starting in 1912. Using these data, would introduce a break in our time series.

data-description and sources are available from the authors upon request.

5.3 Global Copper Production Data

For the period from January 1882 to Devember 1993, we derive a monthly measure for global copper production based on monthly data for almost all of the important producers. Using indicator series for this subset of producers, we employ a Kalman filter and dis-aggregate global annual copper production from Stuermer (2018) to monthly frequency following Durbin and Koopman (2012) (see the online appendix for more details). Please see the online appendix for more details.

We use International Copper Study Group data from January 1994 to December 2016. Our series refers to the copper content of smelter production until 1929 and to refined production thereafter. Output includes copper from mining production and recycling.

5.4 Real Ocean Freight Rate Index

To help identify demand shifts in global commodity markets, we develop a real ocean freight rate index over the sample period. It is widely accepted that world economic activity is the most important determinant of demand for transport services and to certain extent, a proxy for global business cycles (see also Klovland, 2005; Stopford, 2009; Isserlis, 1938; Tinbergen, 1959; Kilian, 2009, 2019)). As discussed by Kilian and Zhou (2018), there are many measures of global real activity and some are more appropriate than others for modeling industrial commodity markets. Alternative measures have been proposed based on world industrial production (e.g. Baumeister and Kilian, 2014; Hamilton, ming), commodity prices more broadly (Alquist et al., 2020; Delle Chiaie et al., 2017; West and Wong, 2014), global steel production (Ravazzolo and Vespignani, 2015), or combinations of variables (Baumeister et al., 2020). For the long time period examined here, a monthly global freight rate index is the appropriate measure, as it also embodies an expectational component of commodity demand and can be constructed at monthly frequency (see Kilian and Zhou, 2018).

We collect monthly ocean freight rates for different agricultural, mining and manufacturing goods for routes from San Francisco, New York and New Orleans to different locations in Europe until the First World War. Major sources are the New York Produce Exchange, the Chicago Board of Trade, and the Chamber of Commerce of San Francisco. During the interwar period, we supplement data from the New York Produce Exchange with several other transatlantic and global monthly freight rate indexes. For the period after the Second World War, we use the dry cargo index provided by Stopford,[9] which we supplement by the Baltic Dry Index starting in February 1985. We aggregate the individual series following the methodology outlined in Kilian (2009, 2019). We deflate the data using the U.S. consumer price index. We remove a polynomial instead of a linear trend to better capture the non-declines in real ocean freight rates over this time period (see also Jacks and Stuermer, 2020).

[9]Personal communication.

6 Estimating the Dynamic Effects of Collusion

The purpose of our endeavor is to evaluate collusive conduct and analyze the resulting market dynamics. We construct counter-factual “but-for” paths for price and output, which illustrate how price and output would have evolved if not for the cartel (see Levenstein and Suslow, 2006).

To our knowledge we are the first to use a dynamic structural time series model for this purpose. The methodology makes it possible to identify the various shocks that drive the price at any one moment and that might have an offsetting impact on price. We can also distinguish these shocks from the price and output shocks sourced with cartel actions. This allows us to deal with two notable problems in previous studies: intangible shocks and reverse causality.

The available literature does not distinguish between shocks due to cartel action and other shocks that might drive the price deviations from the “but-for” price (see Marshall and Marx, 2012, p. 79). For example, a copper cartel was active during the Great Depression, which exerted upward pressure on prices. At the same time, there was a negative demand shock exerting downward pressure on prices as the global economy slowed. A reduced-form model cannot easily separate the positive and negative shocks on the price here. It can also not account for the cartel action to be endogenous to price.

In our structural model, the effect of cartel output restriction shocks can be set-identified and distinguished from the effect of other supply shocks, while a manipulative stock-accumulation shock is identified as an inventory shock and its effect is distinguished from the effect of other copper-specific demand shocks.

There are four steps in our methodology: First, we specify a benchmark period and the collusive treatment periods. Second, we compute the "but-for" price and output paths based on a structural vector auto-regressive (VAR) with sign restrictions. Third, we compute economic damages resulting from price distortions and market supply distortions. Finally, we investigate the dynamics over the course of collusive action periods and unwinding periods.

6.1 Specifying a Benchmark Period

We first estimate the effects of supply and demand on prices and output over both a benchmark period, which is clean of collusive action, and the conjectured collusive periods, while controlling for the effects of collusive action.

We make use of a five variable reduced form vector auto-regressive (VAR) model:

$$y_t = A_1 y_{t-1} + ... + A_p y_{t-p} + \Pi D_t + u_t \ . \tag{1}$$

We regress each of the K endogenous variables $y_t = (\Delta S_t, \Delta R_t, Y_t, \Delta Q_t, P_t)'$ on their own lags p and the lags of all other endogenous variables. We incorporate two variables that control for the effect of collusive action and account for the distinguishing attributes of each period of collusive action: ΔS_t refers to changes in the cartel's stock holdings and

ΔR_t denotes cartels' output changes, as specified in the previous section. This is necessary to obtain an adjusted benchmark period, which controls for the effects of collusive action.

To control for cyclical variation in global real economic activity, we include the index of global real shipping freight rates Y_t. We also add the percentage change in world copper production ΔQ_t and the real copper price P_t in real 2013 US-Dollar.[10]. The matrix of deterministic terms, D_t, consists of a constant, a linear trend (to control for a negative trend in prices and possible linear trends in other variables), and monthly dummies during the two World War periods and the 24 months immediately after each war period to allow for global markets to reintegrate.

We include 24 months of lags, which is a standard in the oil related VAR literature (see Kilian and Zhou, 2020). The $K \times K$ matrices A_i, for $i = 1, ..., p$, entail the reduced form coefficients. The vector of reduced form residuals u_t is assumed to be independent and identically distributed white noise. The covariance matrix Σ_u is assumed non-singular such that $u_t \sim (0, \Sigma_u)$.

6.2 Structural VAR Model

The simultaneous determination of prices and quantities is a major issue in studying the effect of cartel action. For example, cartel action may affect prices concurrently that low

[10]The setup of the basic copper market part is motivated by the empirical literature on oil and other commodity markets (see Kilian, 2009; Kilian and Murphy, 2014; Stuermer, 2018; Baumeister and Hamilton, 2019; Zhou, 2020; Herrera and Rangaraju, 2020). We transform world copper production to percentage change, as common practice in this literature. As the real copper price series is already stationary, we do not transform it by taking logs. This allows us to compute the economic damages without an approximation error that would occur otherwise. We have also compared the time series properties of the price series in levels and in logs and did not find major differences in terms of variances, stationarity or autocorrelation.

prices trigger cartel action. To deal with this issue, we use a structural version of the VAR model:

$$B_0 y_t = B_1 y_{t-1} + ... + B_p y_{t-p} + \Pi^* D_t + B_0 \epsilon_t \ , \tag{2}$$

The matrix B_0 governs the instantaneous relationship among the endogenous variables. The inverse of this matrix B_0^{-1} is called the structural multiplier matrix, which relates to the reduced form coefficients of the endogenous variables $A_i = B_0^{-1} B_i$ with the dimension of $B_i = 1, ..., p$ being $K \times K$. The structural form matrix for the deterministic terms is $\Pi^* = B_0^{-1} \Pi$.

The $K \times T$ matrix ϵ is assumed to consist of serially and mutually uncorrelated structural innovations. It relates to the reduced form residuals u_t through the structural multiplier matrix B_0^{-1}, namely $u_t = B_0^{-1} \epsilon_t$, where $u_t = y_t - A_1 y_{t-1} - ... - A_p y_{t-p}$. These equations allow us to express the mutually correlated reduced-form innovations u_t as weighted average of the mutually uncorrelated structural innovation ϵ_t. The elements of the structural multiplier matrix B_0^{-1} are the weights.

To estimate the structural multiplier matrix B_0^{-1}, we impose sign restrictions on its elements. The basic intuition of sign restrictions in our setup is to search for different random shock series that are admissible solutions for the unknown structural shocks given the vector of reduced-form parameters. This depends on whether the implied structural impact matrix satisfies the assumed sign restrictions. As a result, the parameters of the impact multiplier matrix are no longer point-identified but set-identified.

Sign restrictions allow us to identify supply and demand shocks implied by economic theory. For example, a positive demand shock (exogenous shift of the demand curve to the right along the supply curve) will increase price and quantity, whereas a positive supply shock (exogenous shift of the supply curve to the right along the demand curve) will also increase output but decrease price (see Kilian and Murphy, 2014).

Insert Table 2 about here.

The sign restrictions on the impact responses of cartel copper stocks, cartel copper output, world copper output, global real activity, and the real price of copper are summarized in Table 2. These restrictions identify five structural shocks, which we interpret as a collusive stock manipulation shock, a collusive output restrictions shock, a flow copper supply shock, a flow demand shock due to the global business cycle, and a copper market-specific demand shock.

The first shock is intended to capture the respective cartel's unexpected copper stock manipulations. We assume that this shock positively impacts the cartel's inventories, the real copper price, and world copper output, but a negative impact on global real economic activity. We leave the impact of this first shock on cartel copper output unrestricted.

We interpret the second shock as a collusive output restriction shock. We assume that it impacts world copper output and global real activity negatively and the real copper price positively within a month.[11] The effect of this shock on cartel inventories is unrestricted.

The third shock corresponds to the classical notion of a commodity supply shock. We assume that an unexpected inward shift of the supply curve affects the world copper production negatively, global economic activity negatively, but the copper price positively. Following the logic that higher product prices rather inhibit cartel formation and encourages cheating in existing cartels (see Marshall and Marx, 2012), we assume that a negative supply shock leads to an increase in cartel output and a decline in cartel inventories.

Forth, we incorporate a shock to the demand for copper and other commodities that is associated with unexpected fluctuations in the global business cycle. We label this as a 'flow demand shock.' To identify this shock, we make the assumption that a positive shock leads to higher higher real activity, higher world copper output and higher real prices. Following the logic outlined above, the shock is assumed to lead to an increase in cartel output and a decline in cartel inventories.

Finally, we include a residual shock designed to capture idiosyncratic copper demand shocks not otherwise accounted for. This could relate to shifts in the demand for above-ground inventory due to forward-looking behavior or to other copper market-specific demand shocks driven by changes in preferences or technology. For example, upward revisions to the expected future demand for copper all else equal, will result in an instantaneous shift of the contemporaneous demand curve for copper along the oil supply curve and lead to an increase in the real price of copper. As the price increases, world copper output and cartel copper output are assumed to increase and real economic activity to decline.

[11] We normalize all shocks to have a positive effect on price in describing these assumptions.

Rising prices are a disincentive to cartel action and we assume that cartel copper stocks decline.[12]

For the computation of the counter-factual price and output series and the damages, we only use the cartel shocks during the cartel action periods.

This methodology allows us to distinguish between shocks due to cartel action and other shocks that might drive, e.g, the price above or below the "but-for" price.[13] We can separate three different drivers for changes in supply: First, changes in supply that are endogenously determined by e.g. a change in price. Second, changes in supply that are driven by exogenous shocks, e.g. strikes or wars. Third, changes in supply that are driven by cartel action. As a result, our methodology distinguishes between, e.g., production cuts, which an entity might undertake as a reaction to lower prices and are not influenced by any desire to undertake collusive action, and any changes in supply that are driven by capturing economic benefits by means of collusive action.

Finally, based the methodology we can account for reverse causality between the different endogenous variables and to model the instantaneous and long-run effects of structural shocks on the three endogenous variables.

[12]The residual shock may also capture anticipation effects of cartel action. We went through the economic history and contemporaneous journals of each cartel period and could only find evidence for possible anticipation of the cartel action in three out of the eight cartel periods. We may therefore not capture the full extent of price and output damage in our results. The residual shock may also absorb potential exchange rate shocks, as parts of our sample involve currency conversion from British Pounds to U.S. Dollar.

[13]To illustrate the advantages of our methodology, we present results based on the standard work horse reduced form model, which does not control for the endogeneity of cartel action in the online appendix.

6.3 Computing the "But-For" Price and Output Paths

Based on the structural model, a historical decomposition allows us to compute the "but-for" price and output series, which are the counter-factual price and output series without collusive action. We decompose the five endogenous variables into the contributions of the accumulated effects of each structural shock and the deterministic terms. We can then isolate the accumulated effects of the collusive action shocks on price and output. We basically compute what the counter-factual price and output series would have looked like when removing the effects of the cartel action shocks.

We first explain the historical decomposition. We can decompose the five endogenous variables according to:

$$\tilde{y}_t = \sum_{i=0}^{t-1} \phi_i B_0^{-1} \epsilon_{t-i} + \sum_{i=0}^{t-1} \phi_i \Pi^\star D_{t-i} + \Gamma_1^{(t)} y_0 + ... + \Gamma_p^{(t)} y_{-p+1} \ , \tag{3}$$

where ϕ_i are the estimated reduced form impulse responses, which capture the responses of the endogenous variables to one unit shocks i periods ago. They are computed from $\phi_i = J\boldsymbol{A}^i J'$ and $\left[A_1^{(t)}, \cdots, A_p^{(t)}\right] = JA^t$, with $(K \times Kp)$ matrix $J = \left[I_K, 0_{(K\times K)}, \cdots, 0_{(K\times K)}\right]$. The companion matrix $\boldsymbol{A}$ is defined as a $(pK \times pK)$ matrix:

$$
\boldsymbol{A} = \begin{bmatrix} A_1 & \cdots & A_{p-1} & A_p \\ I_K & & 0 & 0 \\ & \ddots & & \vdots \\ 0 & & I_K & 0 \end{bmatrix}.
$$

The matrix B_0^{-1} is estimated structural multiplier matrix of the endogenous variables and $\Pi^{\star}$ is the structural form matrix for the deterministic terms. We denote variables that are derived from the historical decomposition by upper tilde.

The first term on the right hand side of equation 3 contains the sum of the cumulative contributions of the five structural shocks on each of the endogenous variables. The second term is the contributions of the deterministic terms to the endogenous variables. The last term on the right hand includes the cumulative effect of the initial states on the five endogenous variables, which become negligible for stationary processes as $t \to \infty$.

To construct the "but-for" price and output series, we implement four steps. We explain these steps in terms of an example, which is the cumulative effects of the stock accumulation shock $\epsilon_{1,t}$ on the price variable P_t, the fifth variable in our model:

1. We compute the respective structural moving average coefficient matrices $\theta_{51,1}, ..., \theta_{T-1}$, defined as $\theta_{51,t} = \phi_{51,t} B_0^{-1}$.

2. We derive the structural shocks $\epsilon_{1,t} = B_0 u_{1,t}, t = 1, ..., T$.

3. We construct a structural shock series that only includes the shocks during the cartel

action periods, namely $\epsilon_{1,t}^{Action}$. The cartel action period is defined as the time from the start to the end of the cartel's output restrictions or stock accumulations.

4. We compute the following weighted sum for $t = 1, ..., T$, which represents the cumulative effect of the inventory accumulation shock on price:

$$\tilde{P}_t^{SA} = \sum_{i=0}^{t-1} \theta_{51,i} \epsilon_{1,t-i}^{Action} \,. \tag{4}$$

Following analogous steps, we can construct the contribution of the output restriction shock to price:

$$\tilde{P}_t^{OR} = \sum_{i=0}^{t-1} \theta_{52,i} \epsilon_{2,t-i}^{Action} \,, \tag{5}$$

and the cumulative contribution of the stock accumulation shock $\epsilon_{1,t}$ and the output restriction shock $\epsilon_{2,t}$ to output:

$$\tilde{Q}_t^{SA} = \sum_{i=0}^{t-1} \theta_{31,i} \epsilon_{1,t-i}^{Action} \,, \tag{6}$$

and

$$\tilde{Q}_t^{OR} = \sum_{i=0}^{t-1} \theta_{32,i} \epsilon_{2,t-i}^{Action}. \tag{7}$$

We can now line-out how to compute the "but-for" price path $\tilde{P}^{BF}$ and output path $\Delta\tilde{Q}^{BF}$. We do so by subtracting the cumulative contributions of the respective cartel action shocks from the actual price series and the output series:

$$\tilde{P}_t^{BF} = P_t - \tilde{P}_t^{SA} - \tilde{P}_t^{OR}, \tag{8}$$

and

$$\tilde{\Delta}Q_t^{BF} = P_t - \Delta\tilde{Q}_t^{SA} - \Delta\tilde{Q}_t^{OR} \ . \tag{9}$$

The "but-for" paths provide us with the counter-factual evolution of price and output "but-for" the effects of collusive actions.

6.4 Computing Economic Damages of Collusive Action

We compute both price and output damages based on the two set-identified cartel action shocks. Price damage refers to the surplus lost by consumers that is then captured by the cartel due to higher cartel prices. Output damage is defined as the consumer surplus that consumers forgo, as the cartel reduces the quantity of its output. The latter does not include the loss of producer surplus. We therefore do not compute the entire dead-weight loss.

As there are repeated sequences of cartel action and unwinding periods, we face the challenge that the resulting effects from a cartel shock from a prior cartel period contaminate the effects of shocks during a current cartel action period. What we outline in this section is our implementation of two phases in separating out the effects of each realization of a shock on the output and price for any period of our sample record.

In phase 1 we create a $T \times T$ matrix $\tilde{\Lambda}^{SA,P}$ with the cumulative effects of each realization of the stock accumulation (SA) shock $\epsilon_{1,t}^{Action}$ on the real price P_t. The entries of this matrix are defined as:

$$\tilde{\lambda}_{i,j}^{SA,P} = \theta_{51,j} \epsilon_{1,i}^{Action} , \tag{10}$$

where $i = 1, ..., T$ and $j = 1, ..., T$. Each row of matrix $\Lambda^{SA,P}$ includes the cumulative effects of one realization of the stock accumulation shock $\epsilon_{1,t}$ at time t on the real price over the entire sample. It represents the counter-factual development of price if there had been only this one realization of the respective type of shock.

In phase 2, we compute the total price damage from shock ϵ_1. To do so, we construct the price damage attributed to each realization of shock $\epsilon_{1,t}$ during each time period by multiplying each entry of $\tilde{\Lambda}^{SA,P}$ with the copper production Q. To distinguish between the damage during cartel action periods and unwinding periods, we create a $T \times T$ matrix S, which includes zeros and ones. Ones represent the respective cartel action period (e.g. the Secretan copper syndicate) during which the shock was realized. The total price damage from the stock accumulation shock during the action periods is derived as:

$$\tilde{D}^{SA,P,Action} = \sum_{i=1}^{T}\sum_{j=1}^{T} \Lambda_{i,j}^{SA,P} Q_j S_{i,j} \tag{11}$$

We follow analogous steps to compute the total damage of the stock accumulation shock on price during the unwinding periods as well as the total damage of the output restriction shock on price during the action and unwinding periods.

The procedure for the computation of output damages is the same but with an additional step. Before computing the damages, we need to convert the entries in $\tilde{\Lambda}^{SA,Q}$ and $\tilde{\Lambda}^{SA,Q}$ from percentage change to levels.

As output increases exponentially over the sample period, we control for the value of output to obtain a comparable measure of economic damage over time. We therefore report the total damage as a percentage share of the value of total copper output. We also provide the so called "overcharge," which is the average difference between the actual price (or output) and the "but-for" price (output) as a percentage.

7 Empirical Results from the Structural Model

7.1 Estimation and Inference

We rely on Bayesian methods of inference, which are the most common approach in the literature on sign-identified VAR models.[14]

We assume a conventional Gaussian-inverse Wishart prior on the reduced-form pa-

[14]For more details on Bayesian estimation of sign-identified VAR models see Kilian and Luetkepohl (2017).

rameters and an independent uniform prior on the rotation matrices. This allows us to generate a large number of candidate solutions for the structural impact matrix B_0^{-1} given the vector of reduced-form parameters, based on 20,000 draws from the reduced-form posterior with 20,000 draws of the rotation matrix each. To do so, we follow Rubio-Ramirez et al. (2010) and involve a QR decomposition using the Householder transformation to generate matrices with orthogonal shocks. For each candidate solution of the structural impact matrix B_0^{-1}, we compute the set of implied structural impulse responses. If these impulse responses fulfill the sign restrictions, we retain the respective structural model.

To evaluated the posterior of structural impulse responses, we follow the procedure by Inoue and Kilian (2013, 2019) and compute the mode (most likely model) and the joint credible sets of the admissible structural models. These sets account for the dependence of the elements of the structural impulses across the admissible models.

7.2 Structural Shocks

We derive two shock series, which we interpret as collusive action shocks: the collusive output restriction shock series (red) and the collusive stock manipulation shock series (blue), as shown in Figure 3. These two series are the shock series from the most likely model among the admissible solutions, given the reduced form parameters and the sign restrictions. We only consider the identified shocks during the cartel action periods and disregard those during the other periods.[15]

[15]The complete five identified shock series, impulse response functions and the full historical decomposition can be found in the online-appendix. We interpret the realization of shocks outside of the cartel action periods as shocks to the expectation about cartel action. Some of these realizations may also be

Our interpretation is that these shocks represent by construction the unpredictable component of collusive action. This helps us to distinguish price movements due to collusive actions from price changes due to other factors, such as demand or other supply shocks. The output restriction shock is positive during some months, as cartels roll back their action or members start to cheat. The inventory manipulation shock series is sometimes negative, meaning that the cartel reduces its inventories.

Figure 3 about here.

Impulse response functions in figures 4 and 5 show the effect of the two cartel shocks on selected variables. An unexpected decline in the cartel's output equivalent to about two percent of global output leads to a persistent USD 200 increase in the real price of copper. This type of shock first decreases global output but after about 5 to 10 months global output rebounds, as restrictions lift or production outside of the cartel responds.

We estimate that an unexpected increase in the cartel's inventories equivalent to a bit more than 1 percent of world production, increases global output relatively persistently by about 1 percent and prices by nearly USD 300 for about 15 months.

Figure 4 about here.

driven by measurement issues. We are not too concerned about these shocks outside of the cartel action periods, because the variation of the shock series is much lower than during the cartel action periods. For the output restriction shock series the variance is 8.6 during the cartel action periods and 0.7 during the non-cartel action periods. For the stock accumulation shock the variance is 17 during the action and 0.6 during the non-action periods.

Figure 5 about here.

7.3 The Effects of Collusive Action on Prices

Based on our model, we find that stock manipulation and output restriction shocks drive up the price during the action period. However, both lead to moderately and persistently depressed prices in the unwinding period.

Let's have a look at Figure 6. The chart compares the actual price (black line) to the "but-for" price without the accumulated effect of the output restriction shock (red) and without the stock manipulation shock (blue). The "but-for" price show the counterfactual development of prices "but-for", or "without", the effects of the respective collusive action. To put it differently the "but-for" price is the price that would have obtained in the industry if not for the cartel.

For example, around 1921 prices would have declined to an estimated USD 1,000 per metric ton, if there had not been stock manipulations by the Copper Exporter Association. During the Great Depression Period, prices would have even fallen below zero without cartel action. However, we can also see that collusive action has depressed prices in the following period, as the blue line is above the black one. This indicates that prices would have been higher during that time without previous cartel action.

Figure 6 about here.

Figure 7 shows how the two different types of cartel action affected prices. For example, stock accumulations by the Secretan Copper Syndicate contributed to raise prices by more than USD 2,000 from 1888 to 1889. However, the action then led to a depressed prices until about 1900 in a distinct post cartel period when the stock overhang had to be drawn down. This is a pattern that we see for all three stock manipulation periods.

Output restriction shocks also drive up prices during the action period and lead to declining prices after the action dissolves. This is best seen during Great Depression. Output restrictions by Copper Exporters Inc cushioned the strong downwards effects of the negative demand shocks by raising prices by more than USD 4,000. However, during some of the post-collusion periods we find a negative effect from these cartel actions.

Figure 7 about here.

7.4 The Effects of Collusive Action on Output

Our results show that output restriction shocks cause declines in production, while stock manipulation shocks lead to increases in output. These effects are quite persistent.

Figure 8 illustrates how persistent the effects of collusive action shocks are on production. The black line depicts the actual level of world copper production. Without the accumulated effects of the collusive stock manipulation shock, the output level would have been significantly lower (blue line), whereas without the effects of the collusive output restriction shock the level of production would have been significantly higher (red line).

The effects set in with the collusive action but then persist until the end of our sample, leading to very long unwinding periods of collusive action.

Figure 8 about here.

Figure 9 shows this result through the lenses of the contribution of each type of shock to output. The stock accumulation shock caused a significant increase in output, while the output restriction shock does the opposite.

Figure 9 about here.

7.5 Price and Output Damages

Based on the estimated "but-for" price and output paths, we derive substantial price and output damages during not only the action periods, but also the unwinding periods.

Our results suggest that output restrictions lead to large price damages. They amount to USD -11.3 bn (in 2013 currency) during cartel action periods (see table 3). This is equivalent to about -7.6 percent of the value of global copper output at the time. The overcharge is a little less than 28 percent, meaning that output restriction shock increased prices on average by that percentage during the cartel action periods. During the unwinding periods, we estimate only a small and ambiguous effect of the output restriction shock on price. The unwinding period goes until the end of the sample.

Table 3 about here.

Our estimated results suggest that the stock manipulation shock also has a quite important effect on price, leading to a total price damage of USD -1.2 bn during the action periods. This amount is moderate, because the stock manipulations took place during the earlier part of the sample, when the market was overall smaller. The price overcharge is about 10 percent. During the unwinding periods, there is a small benefit, as stocks unwind, lowering the price.

The two types of cartel action shocks lead to very different effects on output damage. We estimate that output restrictions led to total output damage of USD -1.0 bn during the action periods, which is less than one percent in terms of the value of copper output. On average, cartel action drove down output by only 2.3 percent, although there is large heterogeneity across the different cartel action periods.

During the unwinding periods, we estimate that the output damage sums up to nearly USD -160 bn, which is on average 3.6 percent of the value of output during the unwinding periods. On average, the output restriction shock decreased output by more than 4 percent during the unwinding periods. The effects of the output restriction shock are very persistent and they accumulate over time.

In contrast, stock manipulations lead to moderately higher output (about 4.2 percent) and a benefit of USD 0.6 bn to consumers during the action periods. During the unwinding periods, these benefits are sustained and accumulate to an estimated USD 67 bn, which is on average 1.5 percent of the value of output during these times.

The 68% joint highest posterior density sets obtained from the posterior distribution of the structural models show that the damages are imprecisely estimated for output damages and during the unwinding periods. Measurement issues in the historical monthly data-series for the cartel action variables may be one explanation for this result. Another may be a gap in the theoretical econometrics literature on the estimation of time series models, which include variables with many zero entries.

Overall, output restrictions lead to substantial price damages during the action periods and even stronger output damages during the unwinding periods. In contrast, stock manipulations also lead to strong price damages, but these are more than offset by the benefits from higher output. Output damages by-far exceed price damages in terms of 2013 USD. Total damages during the unwinding periods out-weight those during the action periods.

8 Sensitivity Analysis

Considering the historical nature of our data, several alternative specifications and data-sets yield qualitatively and quantitatively similar results when compared to our baseline.

We first checked for robustness to different specifications in the construction of the cartel output and inventory variables. In alternative specification 1, we use only decreases in output and increases in inventories during the cartel action period and set all other months to zero. In alternative specification 2, we include both increases and decreases during the action periods (like in the baseline specification) but also use available information about the quantities of output increases and inventory decreases during the unwinding periods.

We check the for the robustness of results to including a different price series, namely the New York real copper price in an alternative specification 3. There have been some U.S. tariffs on copper, especially during the interwar period, and the two-price system during post-second world war period, which could both affect results.

We revisit the sensitivity of results to possible structural change. We vary the sample period and run a regression from the beginning of the sample until the end of the interwar period (alternative specifications 4a and 4b). This is an important check, as cartels in the second half of the sample were far less common and powerful than in the first one. Especially, after the dissolution of CIPEC in 1988, there were no official cartel in place.

Finally, in alternative specification 5 we assume that the variance of the two structural cartel shock series does not exceed a value of 0.5 during the non-cartel action periods. This further suppresses cartel action shocks outside of the cartel action periods.

The result that output restrictions lead to substantial price damages but only minimal and ambiguous damages during the unwinding periods is qualitatively and quantitatively quite robust across the different specifications. The price damage during the action periods is about a third higher in alternative specification 1, which seems natural as the specification leaves out upward adjustments to output made by cartels (see table 5 in the online appendix) during action periods. The price damage during the unwinding periods is moderately to substantially larger when using U.S. real copper prices (alternative specification 3, table 6), in alternative specification 5, and when using a sub-sample from 1882 to 1939. In the latter case, the period after the second world war with only very modest cartel action is left out and that's why the damage seems relatively high compare to the baseline specification (see table 8 in the online appendix).

The relatively high price damage from stock accumulation during the action periods in our baseline specification is actually the lowest estimate across all specifications, but the result holds qualitatively. During the unwinding period, the damage is relatively small and ambiguous across specifications. The exception are alternative specifications 4a and 4b with the sub-samples until the end of 1939 and 1988 respectively, which likely can be explained by missing outbalancing effect over the long-run (see tables 8 and 9 in the online appendix).

The result that output restrictions lead to moderate output damage during the action is qualitatively and quantitatively quite robust across specifications. The effect of output restrictions on damage during the unwinding periods is only qualitatively robust. Including available information on cartel output changes during the unwinding period (specification 2, table 6, online appendix) and using a shorter sample period from 1882 to 1939 (specification 4a, table 8, online appendix) result in substantially lower output damage from output restrictions during the unwinding period. At the same time, using New York copper prices (specification 3, table 7), using additional restrictions (specification 5) and including only cartel output declines lead to substantially higher output damage during the unwinding period.

The result that stock manipulations lead to moderate output benefits to consumers during the action periods and substantial output benefits during the unwinding periods is qualitatively and quantitatively moderately robust. When including all information about cartel action (alternative specification 2) and when using NY prices (alternative specification 3), the benefits during the action period turn into moderate damages. Benefits turn into large damages during the unwinding period when only using the increases in stock accumulations (alternative specification 1).

All specifications show that the output damage is far larger than the price damage. They all result in output damage being much larger during the unwinding period than during the action period. The only exception from the latter is quite naturally specification 4a with the much shorter sample period. Earlier results based on annual data and vector auto-regressive system with the cartel action variables as exogenous variables also confirm these two key empirical findings.

9 Conclusion

Our analysis provides evidence of the dynamic market effects of attempted collusion in the global copper market covering from 1882 to 2016. In contrast to the standard workhorse economic model for evaluating the market effects of collusion, our dynamic structural model not only endogenizes the formation of cartels, but distinguishes the cartel market manipulations from other non-cartel shocks, including copper supply shocks, demand shocks due to the global business cycle, as well as copper market specific demand shocks.

We accomplish this separation through the specification of a dynamic structural vector autoregressive model with sign restrictions allowing the identification of collusive action shocks, separately from the other types of specified shocks. To our knowledge, there have been no empirical attempts to separate market manipulative shocks from the other many shocks that naturally take place over a long time series.

Our methodology tracks the dynamic effects of each realization of any cartel action shock on the jointly determined price, output, and cartel actions. For each cartel episode, we compute price and output damages not only during the cartel action periods but as well over the course of each and every unwinding period.

Among our empirical results, we find that cartel action shocks have a strong impact on price and output not only during the cartel action period, but also over subsequent unwinding periods. A second major result is that output damages for cartel actions dominate price damages. This outcome reflects collusive actions that had persistent effects on output beyond the collusive action periods. From the two types of cartel actions, we find that collusive output restrictions lower the output path over the long run while collusive stock manipulations lead to a higher level of output. These combined results suggest that antitrust regulations should focus not just on price damages but as well the output damages that adversely affect consumer surplus.

10 Authors' affiliations

Martin Stuermer is with the Research Department of the Federal Reserve Bank of Dallas. Gordon Rausser is the Robert Gordon Sproul Distinguished Professor Emeritus, Dean Emeritus, College of Natural Resources, and Professor of the Graduate School at the Uni-

versity of California, Berkeley.

References

Agostini, C. A. (2006). Estimating market power in the U.S. copper industry. *Review of Industrial Organization*, 28(1):17–39. https://doi.org/10.1007/s11151-006-0006-8.

Alquist, R., Bhattarai, S., and Coibion, O. (2020). Commodity-price comovement and global economic activity. *Journal of Monetary Economics*, 112:41–56. https://doi.org/10.1016/j.jmoneco.2019.02.004 .

American Bureau of Metal Statistics (1963). *Yearbook of the American Bureau of Metal Statistics*. American Bureau of Metal Statistics.

American Bureau of Metal Statistics (Various Volumes). *Non-Ferrous Metal Data*. American Bureau of Metal Statistics, New York City, NY.

Andrews, E. B. (1889). The late copper syndicate. *The Quarterly Journal of Economics*, 3(4):508–516.

Asker, J., Collard-Wexler, A., and De Loecker, J. (2019). (Mis)allocation, market power, and global oil extraction. *American Economic Review*, 109(4):1568–1615. https://doi.org/10.1257/aer.20171438.

Ayres, R. U., Ayres, L. W., and Råde, I. (2013). *The life cycle of copper, its co-products and byproducts*, volume 13. Springer Science & Business Media.

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

Baker, J. B. and Rubinfeld, D. L. (1999). Empirical methods in antitrust litigation: Review and critique. *American Law and Economics Review*, 1(1/2):386–435. https://doi.org/10.1093/aler/1.1.386.

Baumeister, C. and Hamilton, J. D. (2019). Structural interpretation of vector autoregressions with incomplete identification: Revisiting the role of oil supply and demand shocks. *American Economic Review*, 109(5):1873–1910. https://doi.org/10.1257/aer.20151569.

Baumeister, C. and Kilian, L. (2014). What central bankers need to know about forecasting oil prices. *International Economic Review*, 55(3):869–889. https://doi.org/10.1111/iere.12074.

Baumeister, C., Korobilis, D., and Lee, T. K. (2020). Energy markets and global economic conditions. Technical report, National Bureau of Economic Research. https://doi.org/10.3386/w27001.

Bernheim, B. D. (2002). Expert report of B. Douglas Bernheim. *Re Vitamins Antitrust Litigation, MDL No*, 1285.

Bolotova, Y., Connor, J. M., and Miller, D. J. (2008). The impact of collusion on price behavior: Empirical results from two recent cases. *International Journal of Industrial Organization*, 26(6):1290–1307. https://doi.org/10.2139/ssrn.991908.

Bos, I. and Harrington, Jr, J. E. (2010). Endogenous cartel formation with heterogeneous firms. *The RAND Journal of Economics*, 41(1):92–117. https://doi.org/10.1111/j.1756-2171.2009.00091.x.

Brander, J. A. and Ross, T. W. (2006). Estimating damages from price-fixing. *Canadian Class Action Review*, 3(1):335–369.

Branger, N., Flacke, R. M., and Gräber, N. (2020). Monopoly power in the oil market and the macroeconomy. *Energy Economics*, 85:104597. https://doi.org/10.1016/j.eneco.2019.104597.

Canova, F. and De Nicolo, G. (2002). Monetary disturbances matter for business fluctuations in the G-7. *Journal of Monetary Economics*, 49(6):1131–1159. https://doi.org/10.1016/s0304-3932(02)00145-9.

Connor, J. M. and Bolotova, Y. (2006). Cartel overcharges: survey and meta-analysis. *International Journal of Industrial Organization*, 24(6):1109–1137. https://doi.org/10.1016/j.ijindorg.2006.04.003.

Crowson, P. (2007). The copper industry 1945-1975. *Resources Policy*, 32(1):1–18. https://doi.org/10.1016/j.resourpol.2007.03.004.

Day, D. T., editor (1888). *Mineral Resources of the United States. Calendar Year 1887.* Government Prining Office, Washington, D.C. https://doi.org/10.3133/70175762.

Day, D. T., editor (1890). *Mineral Resources of the United States. Calendar Year 1888.* Government Prining Office, Washington, D.C. https://doi.org/10.3133/70175763.

Day, D. T., editor (1892). *Mineral Resources of the United States. Calendar Years 1889 and 1890.* Government Prining Office, Washington, D.C. https://doi.org/10.3133/70175764.

De Roos, N. (2006). Examining models of collusion: The market for lysine. *International Journal of Industrial Organization*, 24(6):1083–1107. https://doi.org/10.1016/j.ijindorg.2006.04.004.

Delle Chiaie, S., Ferrara, L., and Giannone, D. (2017). Common factors of commodity prices. *ECB Working Paper*, (2112). https://doi.org/10.2139/ssrn.3046410.

Durbin, J. and Koopman, S. J. (2012). *Time series analysis by state space methods*. Oxford University Press. https://doi.org/10.1093/acprof:oso/9780199641178.001.0001.

Edelstein, D. (1999). *Metal prices in the United States through 1998*, chapter Copper, pages 39–42. US Department of the Interior, US Geological Survey.

Elliott, W. Y., May, M. E. S., Rowe, J. W. F., Skelton, A., and Wallace, D. H. (1937). *International control in the non-ferrous metals*. Macmillan New York.

Erutku, C. (2012). Testing post-cartel pricing during litigation. *Economics Letters*, 116(3):339–342. https://doi.org/10.1016/j.econlet.2012.03.033.

Faust, J. (1998). The robustness of identified VAR conclusions about money. In *Carnegie-Rochester Conference Series on Public Policy*, volume 49, pages 207–244. https://doi.org/10.1016/s0167-2231(99)00009-3.

Federal Trade Commission (1947). *Report on the Copper Industry*. U.S. Federal Government.

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

Fisher, F. M., Cootner, P. H., and Baily, M. N. (1972). An econometric model of the world copper industry. *The Bell Journal of Economics and Management Science*, 2(3):568–609. https://doi.org/10.2307/3003038.

Gates, W. B. (1969). *Michigan copper and Boston dollars: an economic history of the Michigan copper mining industry*. Russell & Russell.

Green, E. J. and Porter, R. H. (1984). Noncooperative collusion under imperfect price information. *Econometrica: Journal of the Econometric Society*, 52(1):87–100. https://doi.org/10.2307/1911462.

Guzmán, J. I. (2018). The international copper cartel, 1935–1939: the good cartel? *Mineral Economics*, 31(1-2):113–125. https://doi.org/10.1007/s13563-017-0126-7.

Hamilton, J. D. (forthcoming). Measuring global economic activity. *Journal of Applied Econometrics*. https://doi.org/10.1002/jae.2740.

Harrington, J. E. (2004). Post-cartel pricing during litigation. *The Journal of Industrial Economics*, 52(4):517–533. https://doi.org/10.1111/j.0022-1821.2004.00238.x.

Hartman, R. S. and Doane, M. J. (1987). The use of hedonic analysis for certification and damage calculations in class action complaints. *Journal of Law, Economics, & Organization*, 3(2):351–372. https://doi.org/10.1093/oxfordjournals.jleo.a036935.

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

Herrera, A. M. and Rangaraju, S. K. (2020). The effect of oil supply shocks on US economic activity: What have we learned? *Journal of Applied Econometrics*, 35(2):141–159. https://doi.org/10.1002/jae.2735.

Inoue, A. and Kilian, L. (2013). Inference on impulse response functions in structural VAR models. *Journal of Econometrics*, 177(1):1–13. https://doi.org/10.1016/j.jeconom.2013.02.009.

Inoue, A. and Kilian, L. (2019). Corrigendum to "inference on impulse response functions in structural var models"[j. econometrics 177 (2013) 1–13]. *Journal of Econometrics*, 209(1):139–143. https://doi.org/10.1016/j.jeconom.2017.08.020.

Isserlis, L. (1938). Tramp shipping cargoes, and freights. *Journal of the Royal Statistical Society*, 101(1):53–146. https://doi.org/10.2307/2980654.

Jacks, D. S. and Stuermer, M. (2020). Dry bulk shipping and the evolution of maritime transport costs, 1850-2020. Technical report, MPRA.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *The American Economic Review*, 99(3):1053–1069. https://doi.org/10.1257/aer.99.3.1053.

Kilian, L. (2019). Measuring global real economic activity: Do recent critiques hold up to scrutiny? *Economics Letters*, 178:106–110. https://doi.org/10.1016/j.econlet.2019.03.001.

Kilian, L. and Luetkepohl, H. (2017). *Structural vector autoregressive analysis*. Cambridge University Press, Cambridge, U.K. https://doi.org/10.1017/9781108164818.

Kilian, L. and Murphy, D. P. (2014). The role of inventories and speculative trading in the global market for crude oil. *Journal of Applied Econometrics*, 29(3):454–478. https://doi.org/10.1002/jae.2322.

Kilian, L. and Zhou, X. (2018). Modeling fluctuations in the global demand for commodities. *Journal of International Money and Finance*, 88:54–78. https://doi.org/10.1016/j.jimonfin.2018.07.001.

Kilian, L. and Zhou, X. (2020). The econometrics of oil market VAR models. *Dallas Fed Working Paper*, (2006). https://doi.org/10.24149/wp2006.

Klovland, J. (2005). Commodity market integration 1850-1913: evidence from Britain and Germany. *European Review of Economic History*, 9(02):163–197. https://doi.org/10.1017/s1361491605001449.

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

Lenz, R. (1910). *Der Kupfermarkt unter dem Einflusse der Syndikate und Trusts*. Verlag für Fachliteratur.

Levenstein, M. C. and Suslow, V. Y. (2006). What determines cartel success? *Journal of Economic Literature*, 44(1):43–95. https://doi.org/10.1257/002205106776162681.

Luengo Morales, A. (2015). *Essays on the industrial organisation of the international copper industry*. PhD thesis, University of Southampton.

Marshall, R. C. and Marx, L. M. (2012). *The economics of collusion. Cartels and bidding rings*. MIT Press. https://doi.org/10.7551/mitpress/9011.001.0001.

McNicol, D. L. (1975). The two price systems in the copper industry. *The Bell Journal of Economics*, 6(1):50–73. https://doi.org/10.2307/3003215.

Metal Information Bureau, editor (1933). *Quin's Metal Handbook and Statistics*. Metal Information Bureau.

Metal Information Bureau, editor (1935). *Quin's Metal Handbook and Statistics*. Metal Information Bureau.

Metal Information Bureau, editor (1938). *Quin's Metal Handbook and Statistics*. Metal Information Bureau.

Metal Information Bureau, editor (1939). *Quin's Metal Handbook and Statistics*. Metal Information Bureau.

Mikesell, R. (1979). *The World Copper Industry: Structure & Economic Analysis*. John Hopkins University Press.

Nappi, C. (1979). *Commodity market controls: a historical review*. Lexington Books.

O'Rourke, K. and Williamson, J. (1994). Late nineteenth-century Anglo-American factor-price convergence: were Heckscher and Ohlin right? *The Journal of Economic History*, 54(4):892–916. https://doi.org/10.1017/s0022050700015539.

Pettengill, R. B. (1931). The United States copper industry and the tariff. *The Quarterly Journal of Economics*, 46(1):141–157. https://doi.org/10.2307/1883924.

Pindyck, R. S. (1979). The cartelization of world commodity markets. *The American Economic Review, Papers & Proceedings*, 69(2):154–158.

Radetzki, M. (2008). *A handbook of primary commodities in the global economy*. Taylor & Francis. https://doi.org/10.1017/cbo9780511493584.

Radetzki, M. (2009). Seven thousand years in the service of humanity—the history of copper, the red metal. *Resources Policy*, 34(4):176–184. https://doi.org/10.1016/j.resourpol.2009.03.003.

Ravazzolo, F. and Vespignani, J. L. (2015). A new monthly indicator of global real economic activity. Technical report, Working Paper. https://doi.org/10.2139/ssrn.2602494.

Richard, D. (1978). A dynamic model of the world copper industry. *Staff Papers*, 25(4):779–833. https://doi.org/10.2307/3866605.

Richter, F. E. (1916). The Amalgamated Copper Company: A closed chapter in corporation finance. *The Quarterly Journal of Economics*, 30(2):387–407. https://doi.org/10.2307/1884999.

Richter, F. E. (1927). The copper-mining industry in the united states, 1845-1925. *The Quarterly Journal of Economics*, pages 236–291. https://doi.org/10.2307/1883502.

Rothwell, R. P. and Rossiter, W. R. (1887). The copper outlook, prices and production. *The Engineering and Mining Journal*, 44(25):445–446.

Rubio-Ramirez, J. F., Waggoner, D. F., and Zha, T. (2010). Structural vector autoregressions: Theory of identification and algorithms for inference. *The Review of Economic Studies*, 77(2):665–696.

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

Schmitz, C. (1986). The rise of big business in the world copper industry 1870-1930. *The Economic History Review*, 39(3):392–410. https://doi.org/10.2307/2596347.

Slade, M. (1991). Market structure, marketing method, and price instability. *The Quarterly Journal of Economics*, 106(4):1309–1340. https://doi.org/10.2307/2937966.

Slade, M. E. (1989). The two pricing systems for non-ferrous metals. *Resources Policy*, 15(3):209–220. https://doi.org/10.1016/0301-4207(89)90053-6.

Slade, M. E. (2020). Vertical restraints imposed by buyers: The Sécretan copper cartel, 1887-1889. *Antitrust Law Journal*, 83(1):75–98.

Stopford, M. (2009). Maritime economics. *London: Routledge.*

Struthers, J., editor (1902). *The Mineral Industry. Its Statistics, Technology and Trade during 1901*, volume 10. McGraw-Hill Book Company, Inc.

Stuermer, M. (2018). 150 years of boom and bust: what drives mineral commodity prices? *Macroeconomic Dynamics*, 22(3):702–717. https://doi.org/10.1017/s136510051600050x.

Stuermer, M. and Schwerhoff, G. (2015). Non-renewable resources, extraction technology, and endogenous growth. Dallas Fed Working Papers 1506 (Update version: August 2020), Federal Reserve Bank of Dallas. https://doi.org/10.24149/wp1506.

Temporary National Economic Committee (1940). *Investigation of Concentration of Economic Power, Part 25, Cartels*. U.S. Government Printing Office, Washington D.C.

Tinbergen, J. (1959). Tonnage and freight. *Jan Tinbergen Selected Papers*, pages 93–111.

Uhlig, H. (2005). What are the effects of monetary policy on output? results from an agnostic identification procedure. *Journal of Monetary Economics*, 52(2):381–419. https://doi.org/10.1016/j.jmoneco.2004.05.007.

United States Geological Survey (1893). *Mineral Resources of the United States. Calendar year 1892*. United States Geological Survey. https://doi.org/10.3133/70175767.

United States Geological Survey (1963). *Minerals Yearbook*. United States Geological Survey.

United States Geological Survey (1975). *Minerals Yearbook 1974*. United States Geological Survey.

United States Geological Survey (1976). *Minerals Yearbook 1975*. United States Geological Survey.

United States Geological Survey (1977). *Minerals Yearbook 1976*. United States Geological Survey.

Wagenhals, G. (2012). *The world copper market: Structure and econometric model*, volume 233. Springer Science & Business Media.

Wellmer, F. (1992). The concept of lead time. *Minerals Industry International*, 1005:39–40.

West, K. D. and Wong, K.-F. (2014). A factor model for co-movements of commodity prices. *Journal of International Money and Finance*, 42:289–309. https://doi.org/10.1016/j.jimonfin.2013.08.016.

Zhou, X. (2020). Refining the workhorse oil market model. *Journal of Applied Econometrics*, 35(1):130–140. https://doi.org/10.1002/jae.2743.

A Tables

Table 1: Collusive Action Periods in the World Copper Market

Collusive Entity	**Action Period**	**Actions**
Secretan Copper Syndicate	1887-1889	Stock Accumulations
U.S. and European Producers' Ass.	1892-1893	Output Restrictions
Amalgamated Copper Company	1900-1901	Both
Copper Export Association	1919-1922	Both
Copper Exporters Inc/Copper Institute	1930-1932	Output Restrictions
The International Copper Cartel	1935-1939	Output Restrictions
Production Cuts by U.S. Producers	1962-1963	Output Restrictions
Intergovernmental Council of Copper Exporting Countries (CIPEC)	1974-1976	Output Restrictions

Table 2: Sign restrictions on impact responses in the structural VAR model. All structural shocks have been normalized to imply an increase in the real price of copper. Missing entries mean that no sign restriction is imposed.

	Cartel Cu Stocks	Cartel Cu Output	World Cu Output	Real Activity	Real Cu Price
Cartel Stock Manip. Shock	+		+	-	+
Cartel Output Restr. Shock		-	-	-	+
Flow Supply Shock	-	+	-	-	+
Flow Demand Shock	-	+	+	+	+
Other Demand Shock	-	+	+	-	+

Table 3: Economic damages derived from the structural model using only output restrictions and stock accumulations during cartel action periods based on the most likely (modal) model. Results for the 68% joint highest posterior density sets obtained from the posterior distribution of the structural models are in brackets.

	Price Damage		**Output Damage**	
	Output Restr.	Stock Manip.	Output Restr.	Stock Manip.
Action Periods				
Damage in bn 2013 $	-11.3	-1.2	-1.0	0.6
	[-15.8, -0.1]	[-7.4, -0.2]	[-5.7, 0.3]	[-0.7, 2.7]
Damage in % of Output	-7.6	-6.4	-0.7	2.9
	[-10.6, -0.1]	[-38.9, -0.7]	[-3.8, 0.2]	[-3.6, 14.2]
Overcharge	27.7	9.5	-2.3	4.2
	[0.7, 48.8]	[0.9, 55.0]	[-14.2, 0.6]	[-5.3, 20.0]
Unwinding Periods				
Damage in bn 2013 $	0.8	8.5	-157.5	67.2
	[-253.3, 52.1]	[-84.8, 42.0]	[-1439.8, 219.8]	[-391.2, 266.9]
Damage in % of Output	0.0	0.2	-3.6	1.5
	[-5.8, 1.2]	[-1.93, 1.0]	[-32.9, 5.1]	[-8.9, 6.1]
Overcharge	1.7	-1.2	-4.3	3.1
	[-4.6, 13.3]	[-7.0, 9.1]	[-34.1, 5.3]	[-13.6, 14.8]

B Figures

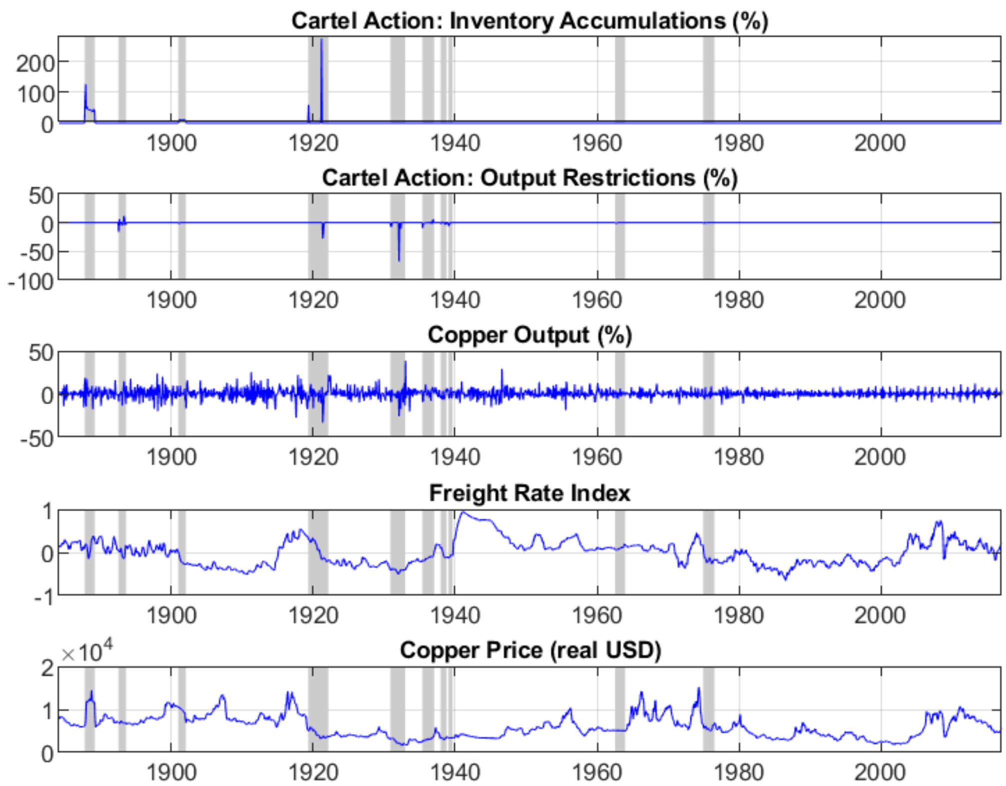

Figure 1: Endogenous variables in the regression.

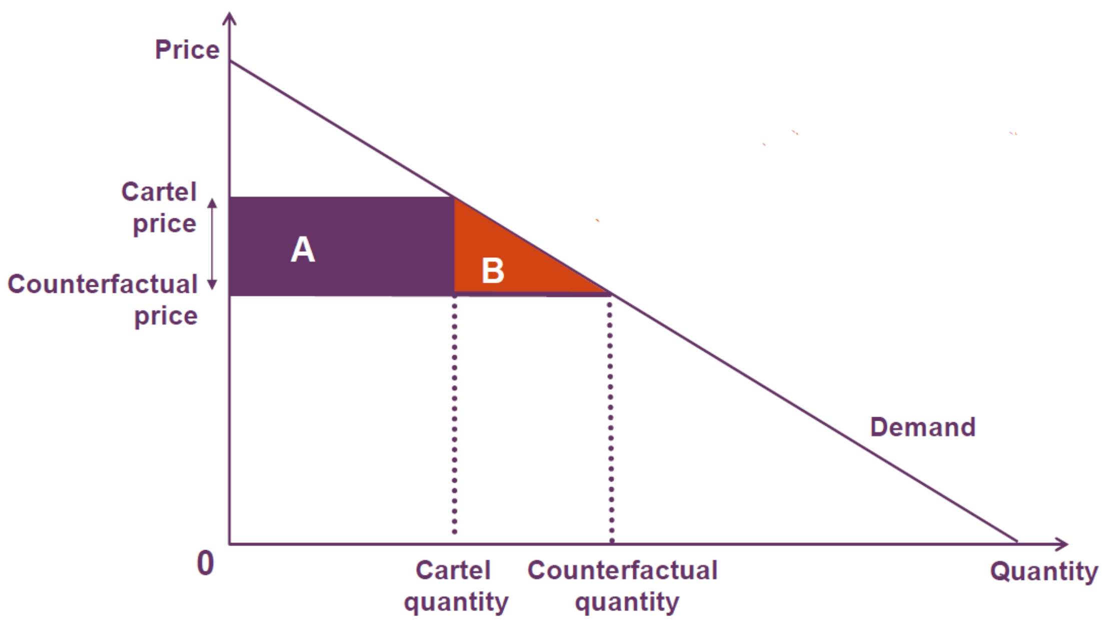

Figure 2: Cartel Price and Output Damage to Consumers.

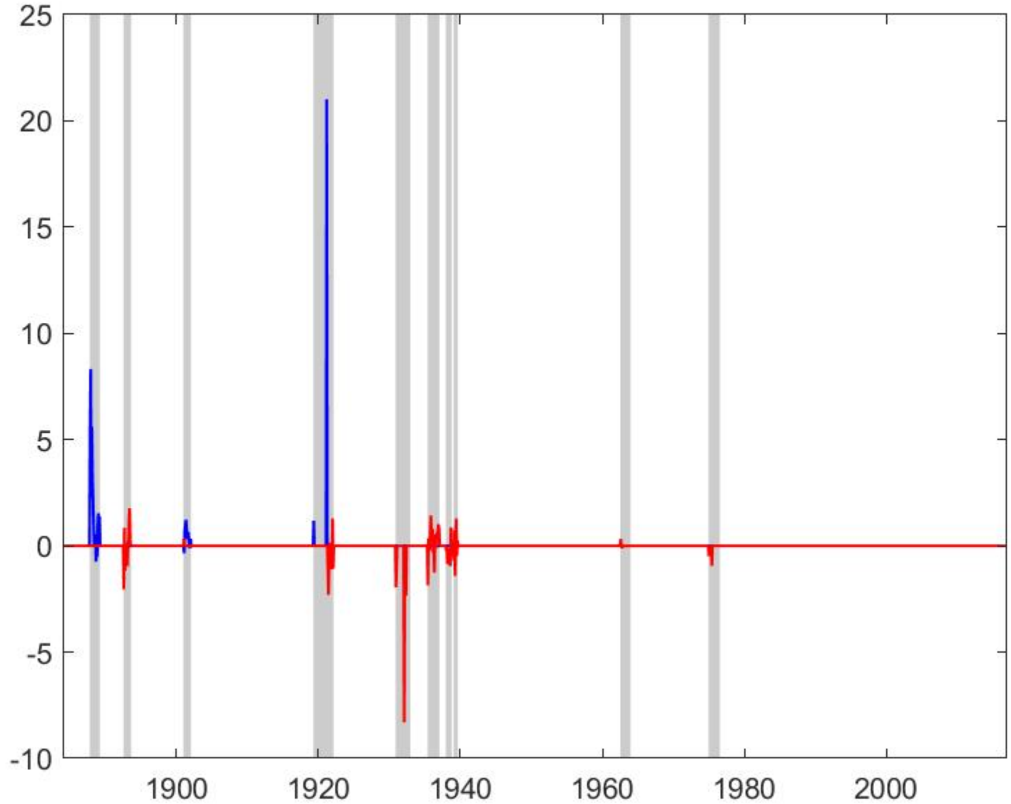

Figure 3: This chart shows the two cartel action shocks, namely the output restriction shock (red) and the stock manipulation shock (blue), during the collusive action periods (grey areas). The two shock series are based on the most likely model and the shocks identified during action periods only.

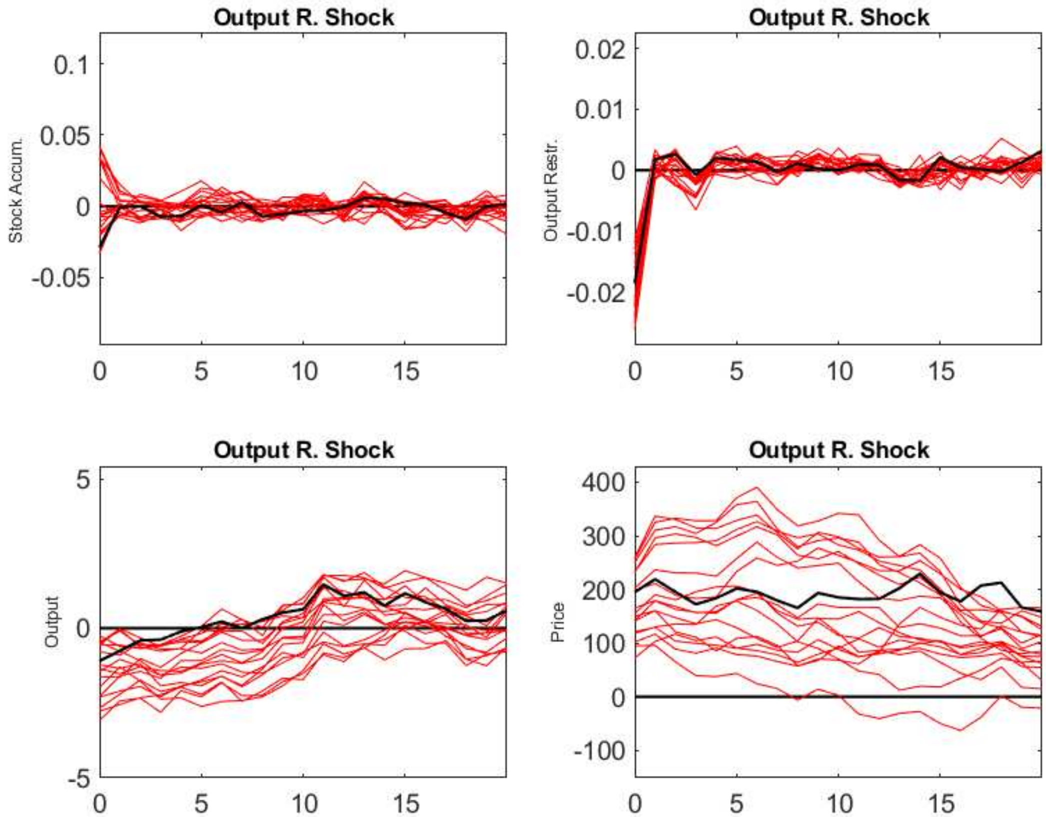

Figure 4: Selected Sign Identified Baseline Model Impulse Response Functions for the Effect of the Output Restriction Shock on Cartel Inventories, Cartel Output, Global Copper Output and the Real Copper Price in the Modal Model and 68% Joint Highest Posterior Density Regions.

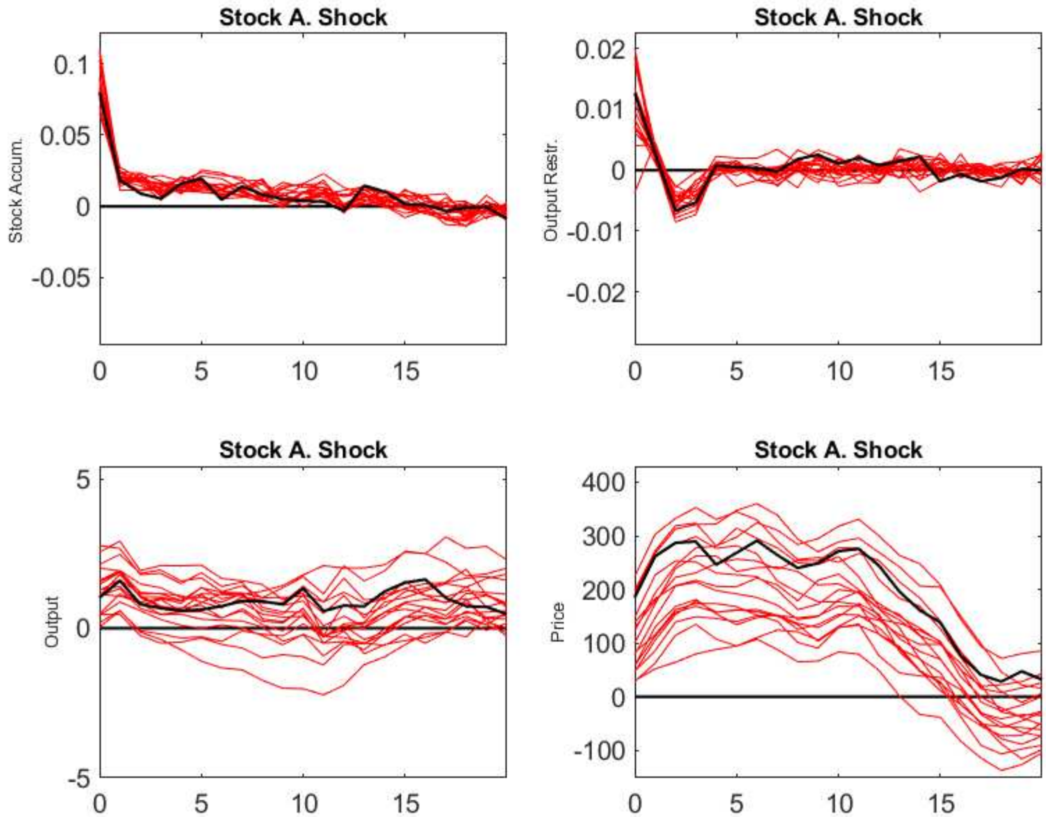

Figure 5: Selected Sign Identified Baseline Model Impulse Response Functions for the Effect of the Stock Accumulation Shock on Cartel Inventories, Cartel Output, Global Copper Output and the Real Copper Price in the Modal Model and 68% Joint Highest Posterior Density Regions.

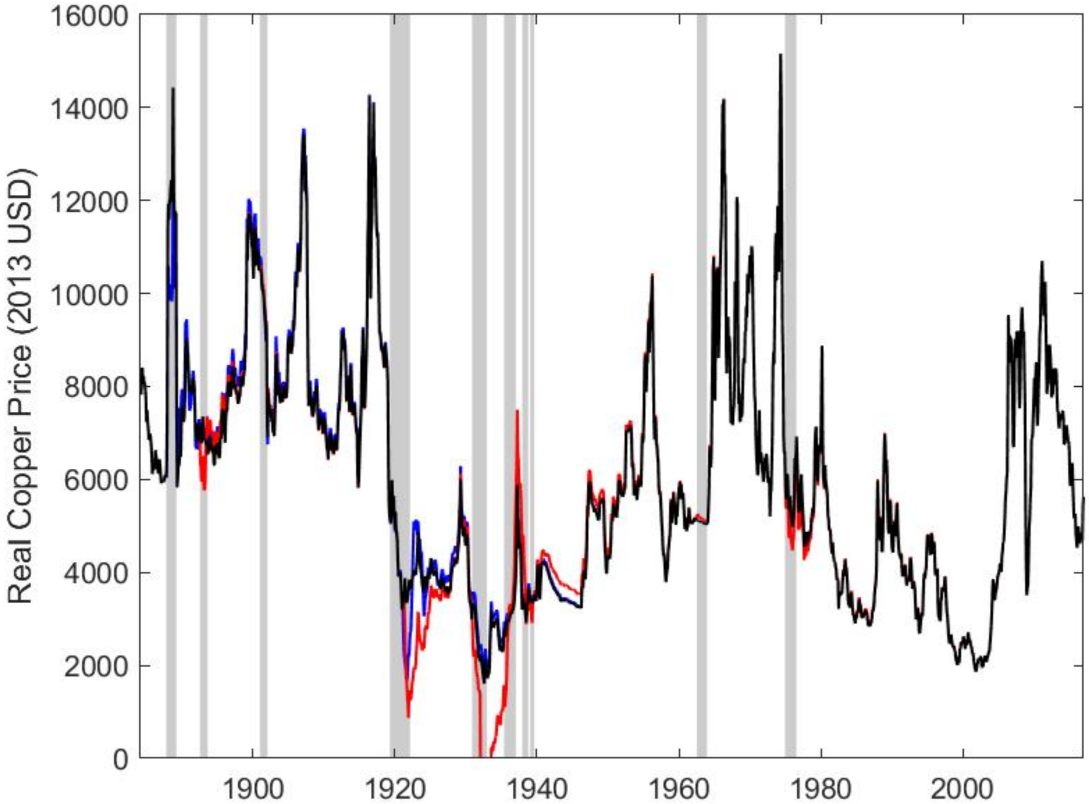

Figure 6: This chart compares the actual real price of copper (black line) to the computed but-for prices without the accumulated effects of the collusive output restriction shock (red line) and the collusive stock manipulation shock (blue line). Grey shaded areas mark collusive action periods.

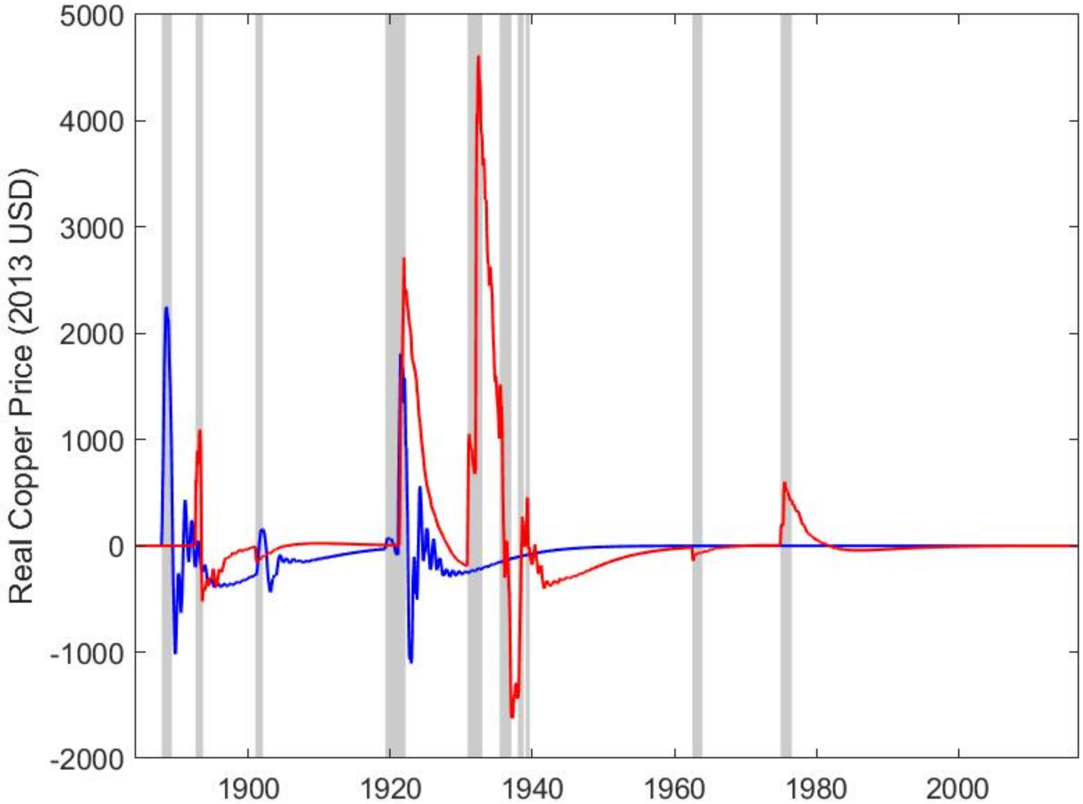

Figure 7: This chart shows the contribution of collusive action shocks, namely the output restriction shock (red line) and the stock manipulation shock (blue line) in explaining the price of copper in 2013 US-dollar. Grey shaded areas mark collusive action periods.

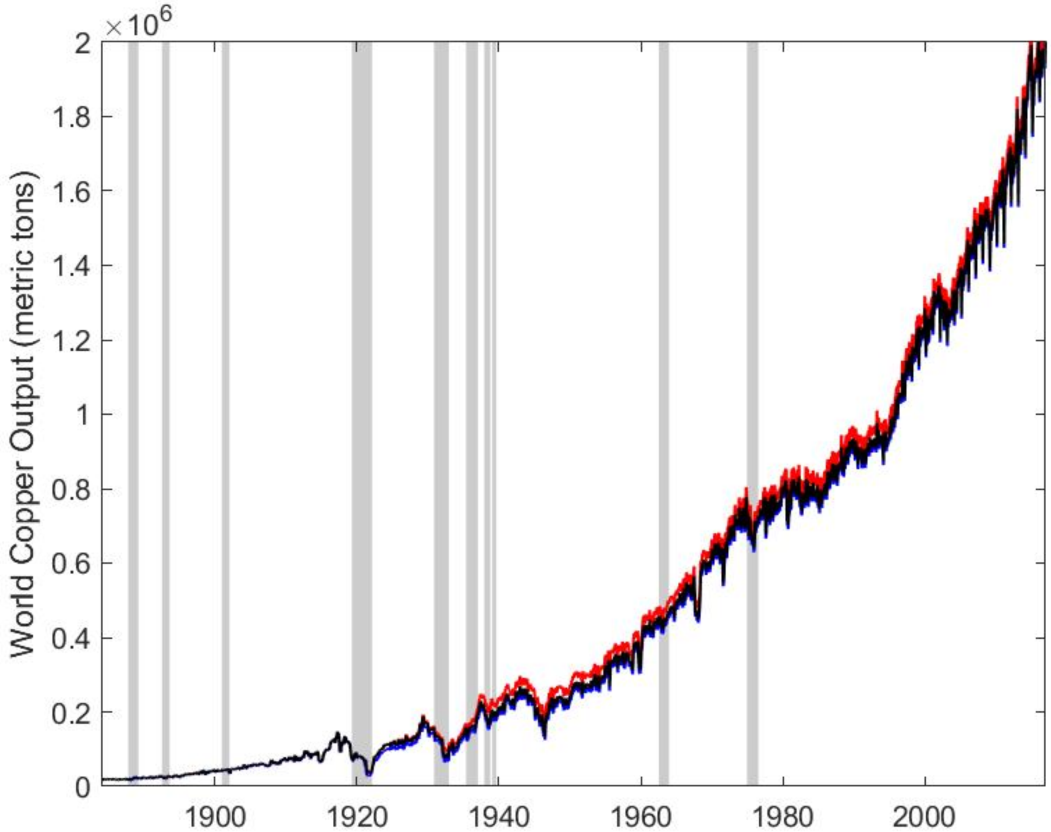

Figure 8: This chart compares the actual level of monthly world copper production (black line) to the “but-for” output without the effects of the collusive stock manipulation shock (blue line) and the output restriction shock (red line). Grey shaded areas mark collusive action periods.

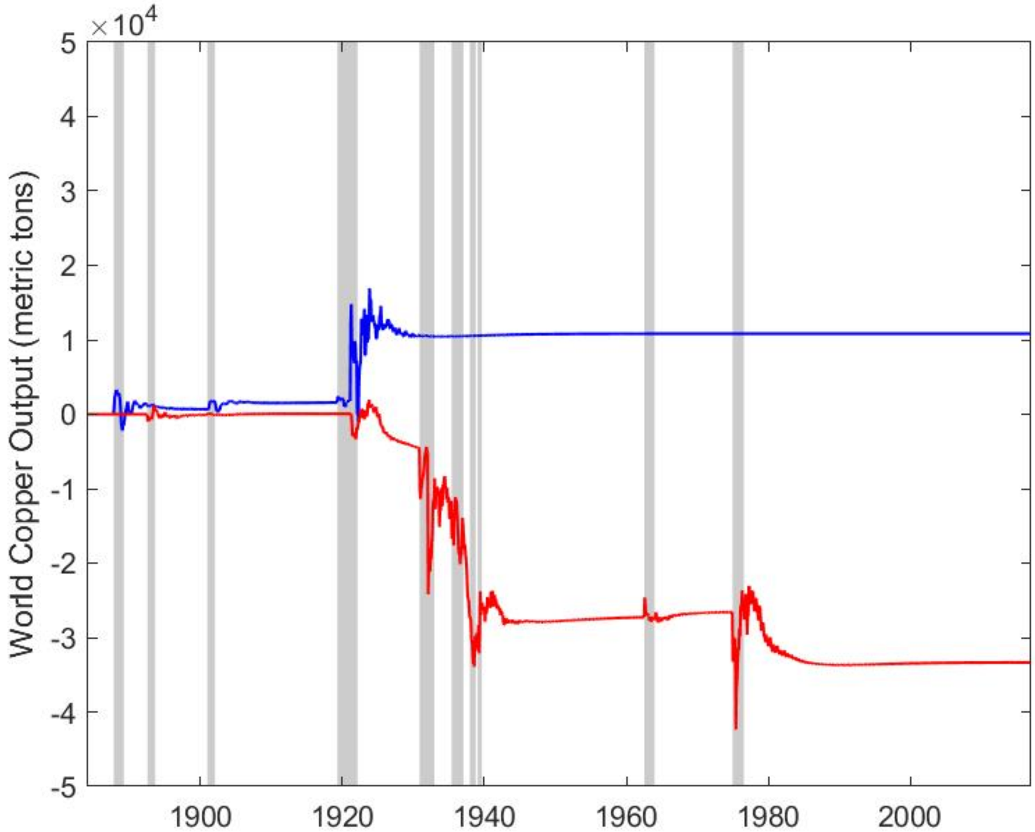

Figure 9: This chart shows the contribution of each collusive action shock, the output restriction shock (red line) and the stock manipulation shock (blue line), in explaining the level of copper output. Grey shaded areas mark collusive action periods.

C Periods of Collusive Action in the World Copper Market

C.1 Secretan Copper Syndicate

Cartel Period: Oct 1887 - Mar 1889 (Andrews, 1889, p. 508)

Output Restrictions: None

Stock Accumulations: Oct 1887 - Feb 1889 (Andrews, 1889, p. 508)

Inducement: The syndicate was encouraged by similar action in tin markets (Andrews, 1889, p. 508; Richter, 1927, p. 258). It also seemed "a propitious time" as consumption was growing faster than production (Andrews, 1889, p. 508; Richter, 1927, p. 258).

Functioning: Slade (2020) provides a detailed account of the syndicate's inner workings. It was a group of copper consumers (the Societe) and investors, which agreed with major producers to purchase a specified maximum amount of production at a fixed price over a period of years (see Herfindahl, 1959, p. 74 and Andrews, 1889, pp. 508-10). There was no agreement to curtail production, but agreements to purchase quantities that were greater than the mines' production in the previous year (see Slade, 2020).

Quantities of Stock Accumulations: The syndicate began to make large purchases of copper in October 1887. It bought nearly the entire stock of chili bars in London, and as much copper as they could obtain in the U.S. (Rothwell and Rossiter, 1887, p. 67). The syndicate controlled 40,823 metric tons of Chili bars by the end of November 1887 (Day, 1888, p. 67). As we are not sure when purchases actually started in October 1887, we assume that one third of the 40,823 mt were acquired during that month. When the syndicate stopped buying copper on March 1, 1889 (see Andrews, 1889, p. 513), the stock of copper throughout the world, mostly associated to the syndicate, was not less than 177,808 mt (Day, 1890, p. 51). We use a linear interpolation to obtain monthly increases in the copper stock from November 1887 to February 1889.

Unwinding Period: The syndicate's stocks were disposed off gradually and in a controlled manner after the breakup of the syndicate (Herfindahl, 1959, p. 76). There were substantial agreements between producers in rolling out the stocks over a couple of years (Andrews, 1889, p. 510; Herfindahl, 1959, p. 76). In June 1889, Paris banks still held 158,757 metric tons of copper in stocks (Andrews, 1889, p. 516). There were another 36,270 metric tons "hoarded" in the U.S. Day (1892) provides some Further details on sales from the former syndicate's stock into the market are available (Day, 1892, p. 72).

Effect on Price (Narrative): Prices rose sharply in 1888. A report by the Engineering and Mining Journal on January 12, 1889, showed that there has been strong overproduction in 1888, as the high price swelled production, scraper copper appeared and consumption was depressed (Gates, 1969, p. 79).

Unwinding Period: The syndicate collapsed in March 1889 and prices declined. Excessive warehouse stocks depressed prices until fall 1892 (Herfindahl, 1959, p. 77). Copper stocks were doled out over a period of 3 to 4 years (1892-3) (Richter, 1927, p. 259).

Share in World Production: There are different estimates in the literature: Andrews (1889, p. 509) states a 80-85% market share, as the syndicate included U.S. producers, Rio Tinto (Spain), and the two Cape copper companies. Lenz (1910, p. 45) provides an estimate of 78% of world production. He lists contracts with the most important producer in Japan, producers in Venezuela, the most important producers in Australia and Chile, the two companies in South Africa, and nearly all important North-American producers. Andrews (1889, p. 509) and Herfindahl (1959, p. 74) mention 80-85%. The authors do not specify whether this number relates to 1887 or 1888. I assume 80% world production in 1888. When summing up per country data, the share of outsiders is larger than 20%. But this might be due to the use of country instead of company data. See also discussion in Richter (1927, p. 258).

Notes: Comptoir D'Escompe, France's largest bank beside the Bank of France, as well as a group of investors, including the Paris Rothschilds, provided funding (Andrews, 1889, p. 510). The responsible manager of the Comptoir D'Escompe committed suicide when the Comptoir D'Escompe collapsed amid a bank run (Andrews, 1889, p. 513).

Timing: There was no anticipation period. The corner was known to be formed only at the end of 1887, when prices doubled see Andrews, 1889, p. 512. The Engineering and Mining Journal mentions the syndicate on Dec 3, 1887 (p. 426) for the first time, and subsequently on Dec 17 (p. 446) and on Dec 24, 1887 (p. 476).

C.2 The 1892 Agreement between the American Producers' Association and the European Producers' Committee

Cartel Period: Jul 1892 - July 1893 (Herfindahl, 1959, p. 78)

Output Restrictions: Jul 1892 - July 1893 (Herfindahl, 1959, p. 78)

Stock Accumulations: None

Inducement: The American Producers Association was formed in 1892 and the European Producers' Committee, including the principal copper mining companies in Spain, Portugal, Germany, the Cape Colony, Mexico and Australia, was created in the same year (Herfindahl, 1959, p. 77). Herfindahl (1959, p. 78) states that the two associations were "...undoubtedly...formed with an eye to collective action to restrict production when advantageous."

Functioning: The cartel collected and disseminated data, except for 1892/1893 when it was directly used for the purpose of restricting output (Herfindahl, 1959, p. 78).

Quantities of Output Restrictions: The cartel agreed that U.S. production should not exceed 142,247 metric tons and exports should not exceed 40,640 metric tons. European producers agreed to reduce output by 5% (Herfindahl, 1959, p. 78-9). In 1893, world output was reduced by 15,876 mt of copper according to Gates (1969, p. 83). United States Geological Survey (1893, p. 99) provides monthly production data for the cartel members' actual output during the period July 1892 to September 1893. The data suggest quite some reductions among U.S. mines. These reductions also more than cover the reduced output worldwide mentioned by Gates (1969, p. 83). U.S. producers' output reductions were apparently helped by the closure of the Anaconda mine for several months. There were seemingly no major reductions among foreign mines. We use the data from United States Geological Survey (1893, p. 99) to compute the output restrictions.

Effect on Price (Narrative): Herfindahl (1959, p. 79) concludes that it was "...doubtful that the 1892 agreement had any important effect on the price?" However, there is strong disagreement with other authors, who claim it was "...the first really effective world copper combination to curtail production." (Gates, 1969, p. 83).

Share in World Production: 75% (Gates, 1969, p. 84 and Herfindahl, 1959, p. 75).

Unwinding Period: Attempts to renew the agreement failed in 1893 "...principally on account of some factors making demands which the other producers did not feel warranted in granting." (Herfindahl, 1959, p.80). The American Producers Association continued operation until 1903 (Herfindahl, 1959, p. 77). We could not find a formal end to the European Producers' Committee.

Timing: There might have been an anticipation effect. The market was already agitated about the formation of a new cartel in March 1892 according to United States Geological Survey (1893, p. 109). The agreement was reached at the end of June (Gates, 1969, p. 82).

Entry and Exit: The Syndicate was the only participant in the cartel. However, it went into contracts with several major producers to purchase copper into its inventory.

We are not aware about any information about the extend that these producers fulfilled their contracts, but we know that the Syndicate's inventory strongly increases during the cartel's existence.

Legal Status: The Syndicate's actions were first clandestine but became public latter on. Our assessment is that the actions were legal at the time.

C.3 Amalgamated Copper Company

Cartel Period: Apr 27, 1899 - Jun 7, 1915 (Richter, 1916, p. 387)

Output Restrictions: Jan 1901 - Dec 1901 (Richter, 1916, p. 387; Herfindahl, 1959, pp. 81-3)

Stock accumulations: Dec 1900 - Dec 1901 (Richter, 1916, p. 387; Herfindahl, 1959, pp. 81-3)

Functioning: The company was founded and directed by Standard Oil and the Rockefellers (Richter, 1916, pp. 288, 402). It was a centralized selling and holding company, which included several important U.S. copper mining companies (Herfindahl, 1959, pp. 80-1). It "...dominated the United States and world copper markets through a complex corporate network." (Schmitz, 1986, p. 396). It imposed output restrictions and was in involved in stock accumulations.

Quantities of Output Restrictions and Stock Accumulations: The company attempted to restrict output in 1899 (Herfindahl, 1959, p. 81). However, mine-level data from Struthers (1902, p. 182) does not provide evidence for significant output reductions in 1899 and 1900. In contrast, in 1901 output was clearly restricted by 919 metric tons (Struthers, 1902, p. 175). In 1900, stockholding increased but not substantially (Lenz, 1910, p. 87). From the end of 1900 to the end of 1901, stockholding of the company increased from 42,184 to 95,254 metric tons (Herfindahl, 1959, p. 82). We interpolate the intermittent monthly stock accumulation data.

Effect on Price (Narrative): Prices rose immediately from 11-13 cents of 1898 to 17-18 cents in 1899 (Herfindahl, 1959, p. 81). Prices stayed high until Dec 1901. However, competitors undersold Amalgamated and its allies. As a consequence, the inventories of Amalgamated went up and reached a peak in 1901. The company concluded that it could not hold up the prices and released copper from its inventories, which depressed prices.

Timing: There might have been an anticipation effect in 1899, when the company was founded.

Share in World Production: 20-40% (own computation). The company controlled about 20% of world production and cooperated with some foreign producers in 1899 (Herfindahl, 1959, p. 81). According to Gates (1969, p. 87), this referred to 95,000 tons of copper per year, which is in line with our world production data for the time. A year later, a new company was set up which handed the sales for Amalgamated and associated interests, totaling about 70 percent of U.S. output (Gates, 1969, p. 87). Herfindahl (1959, pp. 124-5) has also compared the share of the cartel to world output but believes that it was below 70 percent. The companies' market share grew in 1901, when it acquired Boston and Montana Mining Company and the Butte and Boston Company (Herfindahl, 1959, pp. 80).

Unwinding Period: Other producers undersold the Amalgamated Copper Company and world output increased steadily. Amalgamated concluded in 1902 that it could not hold the price up and there were unsuccessful attempts to negotiate output restrictions (Herfindahl, 1959, pp. 81-2). The co-operation with other companies disintegrated completely with the demise of the American Producers' Association in 1903 (Herfindahl, 1959, pp. 81-3). The firm was finally liquidated in 1915, when it took over the name of one of its subsidiaries, the Anaconda Copper Mining Company (see Herfindahl, 1959, p. 80 and Schmitz, 1986, p. 396).

C.4 Copper Export Association

Cartel Period: Dec 1918 - 1923 (Herfindahl, 1959, pp. 93-5)

Output Restrictions: Apr 1921 - Jan 1922 (Temporary National Economic Committee, 1940, pp. 13424-13425)

Stock Accumulations: Apr 1919 - Aug 1921(Temporary National Economic Committee, 1940, p. 13429)

Functioning: As a Webb-Pomerene Institution, the association acted as a sales agent for export sales. It also coordinated a halt in production and purchased copper into its stockpile.

Quantities of Output Restrictions and Stock Accumulations: The association took over the U.S. government stockpile of 50,000 short tons in April 1919 (Herfindahl, 1959, p. 95) and purchased an additional 200,000 short tons of copper in February 1921(see Temporary National Economic Committee, 1940, p. 13429).[16] The members of the association, except for two smaller firms, agreed to cease production from May 1921 to about February 1922 (Herfindahl, 1959, p. 94). Statistics about the unwinding of stocks and production cessation are in Temporary National Economic Committee (1940, pp. 13424, 13425 and 13429). The data shows that firms started cutting their production in April 1919, which we take as the start month and that firms started to revert output restrictions in February 1922. We therefore use January 1922, as the last month of cartel action. All firms followed through according to the data.

Unwinding Period: It took mines from February until May 1920 to fully get back to their March 1919 output. Stocks were released from September 1921 to August 1923 Temporary National Economic Committee (see 1940, p. 13429). It is not clear from the sources what happened to the 50,000 short tons of stock that was taken over from the government in 1919. The association broke up in 1923 owing to "defections, price chiseling, and outside competition" (Herfindahl, 1959, p. 95).

Timing: There was likely no anticipation effect. The association sent a letter to members on February 3 that it will start purchasing copper immediately (Temporary National Economic Committee, 1940, pp. 13416 and 13429). **Effect on Price (Narrative):** The Copper Export Association effectively influenced the market price during its existence, according to Herfindahl (1959, p. 95).

Share in World Production: Our own computation is 65% based on data in Temporary National Economic Committee (1940, p. 13404). Herfindahl (1959, p. 93) estimates 89% of U.S. production and 65% of world production in 1919.

C.5 Copper Exporters, Inc./ Copper Institute

Cartel Period: Oct 1926 - Dec 1932 (Herfindahl, 1959, p. 100 and Temporary National Economic Committee, 1940, p. 13495)

Output Restrictions: November 1930 - November 1932 (Temporary National Economic

[16]The data are for the first day of each month. We therefore start the cartel action in February even though the stock data is for March 1

Committee, 1940, p. 13472, 13477, 13478, 13495 and Federal Trade Commission, 1947, p. 228)

Functioning: The cartel set prices with a loose, voluntary agreement to restrict output. There were provisions that the relative share of members in sales remains constant. Monetary penalties were imposed after July 1930. Both U.S. and foreign firms were included. Selling prices outside the U.S. were determined by a New York committee after consultation with a Brussels committee representing the foreign members. The Copper Institute was established in 1927 to collect data and develop a system of cost accounting. See Herfindahl (1959, pp. 100-2) for more details.

Stock Accumulations: None.

Quantities of Output Restrictions: Meetings to discuss and agree upon output curtailments were held on November 3, 6, 11, and 13 (Temporary National Economic Committee, 1940, p. 13476). A press release was put out on November 14 (Temporary National Economic Committee, 1940, p. 13478). Agreed upon output restrictions totaled 23,665 short tons (Temporary National Economic Committee, 1940, p. 13472, 13477), which was about 15% of world production at the time (Herfindahl, 1959, p. 105). Curtailments were voluntary (Temporary National Economic Committee, 1940, p. 13478) and there was no common start date fixed (Temporary National Economic Committee, 1940, p. 13209). We assume that the restrictions started right after the announcement. It seems that the restrictions stayed on until higher curtailments were agreed upon. In May 1931, further restrictions were discussed according to Herfindahl (1959, p. 105). On December 21, 1931, the Copper Institute finally announced that producers, representing 90% of world production, have agreed to reduce operations to a basis of approximately 26.5% of estimated capacity in 1929 beginning January 1, 1932 (see Elliott et al., 1937, p. 574 and Temporary National Economic Committee, 1940, pp. 13485 and 13486). To compute the quantities of output restrictions, we use the annual average production for the year 1929 as the base year for global production capacity following Herfindahl (1959, p. 105). This assumes that production in 1929 was at full capacity. Finally, in March 1932 the producers met again and producers were asked to cut their production to 20% of capacity as of April 1 (Metal Information Bureau, 1933, p. 74 and Elliott et al., 1937, p. 575). There is to our knowledge no data on actual cartel output available.

Effect on Price (Narrative): During 1926, 1927 and possibly a part of 1928 "...it may well be that CEI's existence prevented prices from declining further."(Herfindahl, 1959, pp. 103) He continues that from 1929 to April 1930 the association successfully stabilized prices and U.S. stocks increased rapidly. The price broke in Apr 1930 owing to price cutting by some firms.Further restrictions could not prevent a very large decline in the price of copper, which reached about 5 cents in mid-1932 (Herfindahl, 1959, pp. 103-5). Overall, Herfindahl (1959, p. 119) describes the cartel as successful in restricting some output at certain periods with some effect on price.

Unwinding Period: In 1932, there was strongly growing divergence among producers, which showed up in differing views on the imposition of a U.S. import tariff on copper (Herfindahl, 1959, p. 105). The association broke up on December 9th 1932 after no further agreement could be agreed up on (see Temporary National Economic Committee, 1940, pp. 13495 and Metal Information Bureau, 1933, p. 75).

Share in World Production: First period: 73-90% (own computation); 65-95% of world production according to different sources quoted in Herfindahl (1959, p. 100). Detailed data on member firms and their output is in U.S. Government (1941, p. 13441-61). Pettengill (1931, p. 148) estimates 90% of world production. Second period: 90%, as it includes Copper Exporters Inc plus several Canadian and South American Mines as well as new Rhodesian production (Temporary National Economic Committee, 1940, 13486). Third period: 48% (own computation); formal members and associated firms accounted for 50% of world production (Herfindahl, 1959, p. 125).

Notes: American copper tariff of 4 cents per lb came into force on June 21 1932 (Metal Information Bureau, 1933, p. 74). No information about media reports at the time. In addition, the National Recovery Administration imposed sales quotas for U.S. producers from April 21, 1934, until May 27, 1935, when the Industrial Recovery was invalidated by the U.S. Supreme Court (Federal Trade Commission, 1947, p. 234). Initial quotas are documented in Temporary National Economic Committee (1940, 13570) and Elliott et al. (1937, p. 586-7). The aggregate maximum production level was 20,500 short tons. However, these quotas were revised downward several times, as they proved to be too optimistic (Herfindahl, 1959, p. 107). There is no information about how the quotas have evolved exactly. The operating procedures were pretty complex and U.S. producers opposed the sales quotas. Primary U.S. copper production was roughly 20,100 short tons in March 1934, so that the quota did not have a cutting effect. The literature suggests that the quotas still had an effect on U.S. prices (and drove a wedge between U.S. and foreign prices in combination with the tariff), as it dampened output increases (see Herfindahl, 1959, p. 107-8 and Elliott et al., 1937, p. 588-9).

C.6 The International Copper Cartel

Cartel Period: March 1935 - September 1939 (Herfindahl, 1959, p. 111 and Federal Trade Commission, 1947, p. 234).

Output Restrictions: May 1935 - December 1936, December 1937 - September 1938, January 1939 - July 1939 (Temporary National Economic Committee, 1940, p. 13434-5)

Stock Accumulations: None

Quantities of Output Restrictions: We use data on the actual cartel output from Temporary National Economic Committee (1940, p. 13434-5). Data on announced output restrictions is also available.

Functioning: The cartel imposed production quotas and made some efforts to control price differentials among products. Members pledged to avoid price cutting. Quotas were only in place when there was weak demand and it seems that copper prices below 10 cents a pound were taken as an indicator. (Herfindahl, 1959, p. 112-3)

Effect on Price (Narrative): Herfindahl (1959, p. 114) asserts that the cartel had some effect on output, but that its effect on price were not great over the entire period.

Share in World Production: Roughly 50% of world output, including both U.S. and foreign firms (Herfindahl, 1959, p. 111).

Anticipation: There might have been some anticipation effects. Discussions among producers started in May 1934 (Metal Information Bureau, 1935, p. 72-3). The agreement was only announced on March 28, 1935. The first output reduction started in May 1935 (see Herfindahl, 1959, p. 110 and Temporary National Economic Committee, 1940, p. 13434). Reintroduction of curtailments in December 1937 was announced in October 1937 (Metal Information Bureau, 1938, p. 79). The decision for the reintroduction of curtailments in January 1939 was made in December 1938. It is not clear that this was announced ahead of time (Metal Information Bureau, 1939, p. 83).

Unwinding Period: There is no easily identifiable unwinding period, as the Second World War broke out in September 1939.

C.7 Voluntary Production Cuts by U.S. Firms

Cartel Period: July 1962 - late 1963 (Crowson, 2007, p. 15)

Output Restrictions: July 1962 - late 1963 (Crowson, 2007, p. 15)

Stock Accumulations: None

Functioning: Voluntary production cuts; "cutbacks in production or sales were introduced in mid July, both in the United States and Africa. Production was reduced by

10-15% in Zambian mines. The cutbacks were reversed late in 1963." (Crowson, 2007, p. 15)

Quantities of Output Restrictions: Output restrictions amounted to 10-15% of Zambian mine output and included cutbacks by U.S. producers (Crowson, 2007, p. 15). Total announced curtailments were 17,000 short tons per month (American Bureau of Metal Statistics, 1963, p. 10). United States Geological Survey (1963, pp. 485,523) lists the following details: On July 11, Phelps Dodge Corp. announced a 6 percent reduction and on September 7 a further cutback was reported; both cutbacks were equivalent to a 10 percent reduction below pre-July levels. The Anaconda Company began a 5 percent curtailment on July 12 at U.S. and Chilean properties, and on July 16 a 9 percent cut was introduced by Inspiration Consolidated Copper Co. Kennecott Copper Corp. announced a 10 percent reduction effective September 9 at its Nevada and New Mexico properties, September 10 at the Utah mine, and September 16 at the Arizona mine. Curtailment also went into effect at the company's Chilean properties. A 10 percent production curtailment by Northern Rhodesian producers, in effect throughout fiscal year 1962, was increased to 15 percent in July. To model this ramp up in production cuts, we assume an output reduction of 4,250 short tons in July 1962, an additional 4,250 short tons in August 1962 and a further reduction of 8,500 short tons in September 1962. Reductions are reversed in December 1963.

Effect on Price (narrative): The collusive action reduced oversupply and helped stabilize prices according to Edelstein (1999, p. 39).

Share in World Production: 38% (own computation derived from data on primary production in Zaire, South Africa, U.S., South Rhodesia, and Zambia from Schmitz (1986).

Anticipation: We could not find information on the timing of decision making.

C.8 Intergovernmental Council of Copper Exporting Countries (CIPEC)

Cartel Period: June 8 1967 - 1988 ((Nappi, 1979, p. 103)

Output Restrictions: December 1, 1974 - June 30, 1976 (United States Geological Survey, 1975, p. 499 and United States Geological Survey, 1976, p. 565)

Stock Accumulations: None

Functioning: The organization used export quotas, which were effectively production cutbacks, according (Mikesell, 1979, p. 106 and United States Geological Survey, 1976, p.

565). The organization served as forum for discussion and dissemination of information. There was ongoing nationalization of copper mines in some member countries (see Nappi, 1979, p. 103). Some of the discussions on stabilizing copper markets were absorbed by UNCTAD's conferences on commodity markets (United States Geological Survey, 1976, p. 565).

Quantities of Output Restrictions: On November 19, 1974, CIPEC announced that, for the six months following December 1, 1974, its member countries would reduce monthly exports by 10% from earlier 1974 levels (United States Geological Survey, 1975, p. 499). In a meeting from April 9 to 11, 1975, CIPEC decided to raised the quota applied to member countries to 15% starting on April 15. We compute the monthly restrictions based on data for CIPEC countries for the year 1974 from American Bureau of Metal Statistics (mes). There are no data on actual output restrictions available at the monthly level.

Unwinding Period: After the end of output restrictions on June 30, 1976, member countries could not agree on further production curtailments (Nappi, 1979, p. 114, 116 and United States Geological Survey, 1977, p. 336).

Effect on Price: The cartel was "not fully observed" and "unsuccessful in stimulating a price rise" according to Mikesell (1979, pp. 187-215). "The effects of this first intervention were very modest..." concludes Nappi (1979, p. 104).

Share in World Production: 21-23% (based on our own computation). Initial members were Chile, Peru, Zaire and Zambia. Since 1975 Australia, Mauritania, Papua New Guinea became associated members and Yugoslavia and Indonesia became full members. The association controlled about 37% of world mine output in 1975 according to Radetzki (2008, p. 158) (see also discussion in Nappi, 1979, p. 114). My computation show that it is less in terms of refined production.

Notes: Some functions of the CIPEC such as data dissemination were continued by the International Copper Study Group formed in 1993 (see Radetzki, 2008, p. 158).