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The by-product effect on metal markets – New insights to the price behavior of minor metals

Patrick Afflerbach [a], Gilbert Fridgen [b], Robert Keller [a], Andreas W. Rathgeber [c,*], Florian Strobel [a]

[a] FIM Research Center, University of Augsburg, 86150 Augsburg, Germany
[b] FIM Research Center, University of Bayreuth, 95440 Bayreuth, Germany
[c] Institute for Materials Resource Management, University of Augsburg, 86150 Augsburg, Germany

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ABSTRACT

We will examine price dependencies between primary products and co-products from metal markets. First, we develop an optimization model to determine the profit-maximizing extraction behavior of mining companies. With this model, we analyze how the companies optimally react to exogenous demand shocks on the metal markets, and how the prices of metallic primary products and their co-products are related to each other. This approach enables us to determine the basic conditions leading to price relationships. Second, we validate our theoretical findings on monthly metal prices from June 2009 to January 2013. We apply a linear regression model to analyze the price relationships of the primary products and their co-products and finally compare the results of our analysis to our model forecasts.

Introduction

Since 1980, the number of chemical elements in industrial use has more than quintupled (Theis, 2007). So-called minor and precious metals in particular are of increasing importance to the world's current industry (Lewis et al., 2011). The unique properties of these metals make them valuable for high tech applications (Hagelüken and Meskers, 2010). Minor metals are used in wind power, photovoltaic, carbon capture, sequestration, the oil sector, supercritical power plants, transports, energy efficient lighting or smart grids (Fizaine, 2013). Due to their rising importance, more and more studies such as European Commission (2010) or European Pathway to Zero Waste (2011) analyze the criticality of minor metals. One element that exemplarily underlines the increasing importance of these metals is selenium. Where it has been previously regarded as a waste product from the mining of copper ores, it is now an important source of revenue for the mining industry (Hagelüken and Meskers, 2010). Today, mining these selenium-containing copper ores is like killing two birds with one stone.

The term *minor metals* cannot be defined completely and precisely. It rather encompasses diverse metals which have several characterizing attributes. Originally, *minor metals* were those metals not traded on major public exchanges apart from a few exceptions (Hagelüken and Meskers, 2010). Furthermore, minor metals are characterized by a relatively low production volume (Fizaine, 2013). Although palladium and platinum are traditionally classified as precious metals, we assign them to the group of minor metals for reasons of simplicity. This is because these two metals feature similar economic properties to minor metals. We do not include gold and silver since these metals have special economic attributes from their role as investment products. The term *base metals* includes aluminum, copper, lead, nickel, tin and zinc, metals which are widely used in industrial applications, have a relatively high production, and are traded on formal exchanges (Hagelüken and Meskers, 2010).

A special attribute of minor metals is that they are mostly produced jointly with base metals (Steinbach and Wellmer, 2010). There are only a few minor metals that are additionally extracted on their own, such as platinum (Hagelüken and Meskers, 2010). Within metallic joint production, there exist two possible set-ups of metal pairs. They are either defined as a combination of a main (or a primary) product and a by-product, or as co-products. Campbell (1985) defines a *by-product* as a secondary product from the extraction process of the *primary product*. The primary product determines the mining decision whereas the by-product has no effect on the profit-maximizing level of production. The by-product just underlies a binary decision: either it is completely sold if it is profitable, or it is not sold if it is not profitable. As a

* Corresponding authors: Tel +49 821 598 3040
E-mail address: andreas.rathgeber@mrm.uni-augsburg.de (A.W. Rathgeber).

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Table 1
Definitions.

1	Minor metals	Minor metals are mostly not traded on major public exchanges, they have relatively low production volumes and they are predominantly extracted as by-products from base metal production (Hagelüken and Meskers, 2010). In addition, we assign the (former) precious metals platinum and palladium to that metal group.
2	Base metals	Base metals are traded on major public exchanges, they have high production volumes, and they are widely used in industrial applications (Hagelüken and Meskers, 2010).
3	Co-product	Co-products determine the extraction strategy along with one or more other co-products and they mutually influence their prices (Campbell, 1985).
4	Primary product	Primary products determine the extraction strategy to a large extent and they influence the prices of the associated metals (Campbell, 1985).
5	By-product (traditional definition)	By-products do not determine the extraction strategy and they do not influence the price of the associated metals (Campbell, 1985).
6	By-product (adapted definition)	By products may influence the extraction strategy but they do not influence the price of the associated metal.

result, the price of the primary product influences the price of the by-product but not vice versa. *Co-products* in contrast directly influence the profit-maximizing production along with one or more other co-products and they mutually influence their prices (Campbell, 1985). As minor metals are typically regarded as by-products of base metals, we also focus on the economic behavior within this set-up. However, we slightly adapt the definitions. Whereas primary products still determine the production decisions in the first line, we show in the following that the present market conditions for minor metal suggest that they should also be included in that decision. However, the one-sided price influence of the primary product on the by-products remains valid within our framework. Summing all up, we can state that our definition of by-products contains the traditional definition attribute of the one-sided price influence and the inclusion to the production decision, a characteristic typically reserved for co-products. Our definition framework is summarized in Table 1.

Due to the rising importance of minor metals, the dynamics and the behavior of their prices are of major interest to producing companies. Existing models for optimal extraction strategies, like the models developed by Hotelling (1931), Campbell (1980), Crabbe (1982), and Lewis (1985), do not consider by-production, neither do traditional econometric models for commodity prices which typically focus on inflation, interest rate and industrial production (Awokuse and Yang, 2003) and exchange rate (Jain and Ghosh, 2013). The main reason for the lack of research within this topic may be the "lack of reliable price and production data" during the 20th century (Fizaine, 2013). This research gap is additionally underlined by Fizaine (2013) who states that economists should further analyze the mechanisms of minor metal markets to limit uncertainty. The preceding analysis leads to the following research question: Does the relationship between minor metals and base metals on the production site result in a price relationship between these metals? We will refer to this potential price relationship as the "by-product effect". To address this research gap, we extend current research results on metallic joint production by the formulation of a quantitative model. With our model, we are able to confirm the existing results and provide additional insights. In a next step, we empirically investigate these price dynamics.

Literature review

By taking a closer look at the economic literature, we find that joint production has been practiced for many years. The topic was initially addressed in economic theories by Adam Smith (1776) and Karl Marx (1867). These two theorists were followed by Merian (1932), Arrow and Debreu (1954) and Riebel (1955), who modeled external effects as by-products. In recent years, authors from several research domains developed different approaches to joint production, covering topics from oil production (Tamunaidu and Bhatia, 2007), chemistry and biology (Ayres, 1995; Blömer and Günther, 1998; Nalle et al., 2004; El-Diwani et al., 2012), the brewing industry (Scheiby, 2009) and general production theory (Sakai, 1974). However, these approaches can hardly be applied to determine optimal extraction strategies within metallic joint production because of two reasons: First, some approaches apply a variable proportion between the primary product and the by-product (El-Diwani et al., 2012), and thereby contradict the constant proportion in metallic joint-production (Hagelüken and Meskers, 2010). Second, some authors focus on other aspects of production strategy, such as speeding up production (Blömer and Günther, 1998) or the minimization of unsuitable outcomes (Nalle et al., 2004).

In addition to the approaches inspired by general production theory, there exist models that include characteristics of metal markets. Campbell (1985) analyzes the metallic joint production using an equilibrium model and an empirical approach. Campbell (1985) bases his theoretical framework on an analysis of the short-run demand and supply behavior of the entire mining industry and finally states that the prices of co-products have a negative relationship when the demand for only one metal shifts, or when the demands for both metals shift in opposite directions (where all other factors are constant). He furthermore reveals that co-product price relationships are indeterminate when demand for the co-products move in the same direction. Campbell finally states that the price cycles of metals develop differently, (demand shifts in opposite direction) which leads to a diversification effect for multi-metal mining. This claim is supported by a sign test for the metal-price-movements of copper, molybdenum, silver, gold, lead, and zinc between 1950 and 1982. However, metal markets have changed since the study was conducted. Chen et al. (2010) analyze positive correlations between the London Metal Exchange Index and nearly every metal, which indicates that the price cycles of metals are not independent anymore. Therefore, this result cannot be directly transferred to the present markets for minor metals. However, the statements about the negative price relationship in demand shifts on one metal market and the indeterminate effects in the case of parallel demand shifts on both metal markets still remain valid.

Fizaine (2013) transfers the results of Campbell (1985) to the present markets of minor metals and empirically analyzes their validity. Concerning the price relationship between minor metals (gallium, indium, molybdenum, selenium, tellurium) and their base metals (aluminum, copper, zinc), he reproduces the results of Campbell (1985). He analyzes price data from 1950 to 2011 on a yearly basis provided by the United States Geological Survey (USGS) and confirms that the prices for minor metals behave independently from the prices of their base metals. However, the