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An empirical approach to determine specific weights of driving factors for the price of commodities—A contribution to the measurement of the economic scarcity of minerals and metals

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A B S T R A C T

In recent years, commodity markets show a large amount of volatility and substantial price jumps, indicating an increasing economic scarcity in many cases. As this scarcity makes commodity procurement a critical issue for national economies, industry sectors and manufacturing companies, a number of criticality indices have been presented and utilized in science as well as in practice. These indices are mostly based on an aggregation of different key figures, both qualitative and quantitative. However, the weighting of the different factors is in most cases arbitrary or based on rough estimates.

While this may be inevitable in some areas, we believe that an empirically based aggregation is desirable and to some degree attainable. While the broad concept of criticality is certainly hard to operationalize from a quantitative point of view, the economic scarcity is not only one important factor of criticality, but can be measured to some extent by the material's market price.

Therefore, in this paper we show that each single raw material comes with a fundamentally different set of relevant factors for its economic scarcity. We determine those by performing an extended regression analysis on the market price (dependent variable) of 42 (out of about 60 industrially relevant) chemical elements, based on a broad range of empirical datasets, covering 11 driving factors (independent variables) and a 26 year time span. Our analysis determines specific weights for the factors of scarcity of each raw material and takes into account the material's individual characteristics.

We expect these results to be valuable for refining the aggregation of criticality assessments, as scarcity is at least one aspect of criticality and many influence factors we analyzed are currently utilized in criticality studies. However, our results are contrary to a number of well-known studies on criticality of raw materials, which assign generic weights to the different driving factors of different commodities and therefrom derive a criticality index. Instead, our results suggest a specific model for every single material when assessing availability risks in criticality evaluation methods. Therefore we hope that our results provide an additional empirical perspective regarding the weighting of factors for criticality based on the economic scarcity of minerals and metals.

Introduction

Commodity markets have been volatile for a long time; in the recent past, however, the magnitude of price fluctuations has increased dramatically and in many cases caused commodity prices to double or even triple within only a few years (e.g. copper or tin, LME, 2012). These price jumps indicate a strongly rising economic scarcity of these metals and put enormous financial stress on many companies and entire economies essentially depending on raw materials (Angerer et al., 2009; U.S. Department of Defense, 2009).

To cope with these risks, companies and economies try to understand current and forecast future raw materials prices and availability in order to facilitate sensible long term planning. However, the level of heterogeneity and complexity of the underlying data requires extensive familiarization, and decision makers are often overburdened with this task that usually does not coincide with their regular responsibilities. Therefore, indicators providing an aggregated estimate of the overall scarcity, or more generally of the "criticality" of raw materials have been developed to support the decision making process (Achzet et al., 2010) and to simplify the development of long term commodity utilization strategies.

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Currently there is a number of widely used approaches for such criticality or scarcity indicators. For instance, Graedel et al. (2012) present a comprehensive framework to assess raw material criticality considering three dimensions: supply risk, environmental implications, and vulnerability to supply restriction. Bauer et al. (2010) from the U.S. Department of Energy use fixed weighting factors for five different criticality aspects. Rosenau-Tornow et al. (2009) present a criticality assessment based on five indicators as well, but aggregated graphically by using a spider web diagram. And the European Commission (2010) promotes a method that basically aggregates supply risks and economic importance, characterizing this as a “pragmatic approach”. In addition, there is a large number of other pragmatic sectoral and company-specific approaches mostly based on a commodity-independent weighted average of the utilized indicators. However, these pragmatic approaches consist of rather arbitrary aggregations based on fixed percentages or other static aggregates that universally apply to all commodities and are not validated quantitatively or empirically. Moreover, most presented methods use different aggregates. In practice, the reliability of these approaches often remains unclear in particular when it comes to their selection of relevant factors and to the aggregation utilized.

Therefore, in this paper we present an empirical analysis based on a number of input factors that determines what factors account for which part of commodity prices. Here, we regard the commodity price as preliminary indicator for scarcity (following Tilton, 2003) and thus for the economical aspects of criticality. By doing so, we want to contribute to an improved understanding of the interrelation between the commodity price, that after the theory of efficient markets represent current and future risks, and a number of common criticality factors like mine production, country concentration or economic growth. While this section presents an introduction and motivation, the following section outlines the relevant literature and the research question. In the Methodology section, we describe our methods and our proceeding, while the results of the different regressions and a number of additional tests are given in the Empirical results section. These results are discussed and interpreted in the penultimate section, while the last section offers an outlook and a short conclusion.

Literature and theory

In the past years, a lot of research has been conducted regarding the economical importance and scarcity of commodities. With the emerging concept of raw material criticality, researchers try to evaluate and assess the correlation between the two topics. It is therefore still a very young and heterogeneous research area, and a broadly accepted definition of criticality has yet to be established. In the context of raw materials, the term first came up in 1939 within the Material Stock Piling Act, that regulated the securing of militarily relevant materials for which availability had become uncertain due to geopolitical developments (National Research Council, 2007). Nowadays, the exact selection and weighting of factors that make a raw material critical or scarce are still open research questions. For instance, raw materials are considered critical if they are highly significant for national economies and if their current or future supply is threatened in any way (European Commission, 2010). In the broadest sense, criticality denotes the extent of current and future risks associated with a certain metal, but this fuzzy definition is certainly hard to operationalize. Moreover, it can be observed that criticality also relates to ecological, social, or political considerations, which makes it a holistic and complex concept (European Commission, 2010; Graedel et al., 2012). All in all, a high criticality index basically at least indicates that the material's current or future usage requires increased attention.

The widespread scientific and practical relevance of criticality and the broad variety of relevant criticality factors is strikingly demonstrated by a number of well-known and frequently discussed studies, for instance Graedel et al. (2012), Massachusetts Institute of Technology (2010), Geological Survey of Finland (2010), Rosenau-Tornow et al. (2009), Wouters and Bol (2009), Waeger et al. (2010), Behrendt et al. (2007), and Smith (2005). Table 1 shows a selection of these and other studies especially focusing on the utilized criticality factors. Category 1 deals with raw materials on a national economy perspective, category 2 analyzes materials from a company's perspective, category 3 from a functional perspective (e.g. mobility, energy), and category 4 discusses raw materials considering specific criteria, such as toxicity or demand trends. Categories 3 and 4 show that criticality assessment highly depends on sector specific aspects or different viewpoints on what is considered a criticality driver. Moreover, the representation shows the heterogeneity and even arbitrariness when selecting and aggregating indicators. It is common to examine the criticality of raw materials according to a top–down method, starting with a rough scan using categories 1 and 2, followed by a detailed analysis using categories 3 and 4.

When taking into account the criteria frequently discussed in the current studies as listed in Fig. 1, it becomes obvious that identifying the criticality of raw materials requires a high amount of interdisciplinary efforts. Information from different disciplines, such as geology, economics, social science and engineering, is indispensable. Thus, the aggregation of these results is by no means easy to accomplish.

In most studies, it is common to define general weightings for each variable. For instance, Rosenau-Tornow et al. (2009) analyze copper supply risks by aggregating the factors *supply/demand*, *geostrategic risks*, *market power*, *supply/demand trends* and *production costs* into a spider web diagram. Bauer et al. (2010), on behalf of the U.S. Department of Energy, also present a selection of the most important criticality criteria which are aggregated by predefined weightings. Here, 40% is assigned to basic availability, 20% to political, regulatory and social factors, 20% to producer diversity, 10% to competing technology demand, and 10% to co-dependence on other markets. Using this specific form of aggregation, Dysprosium has been rated the element with the highest long term supply risk for the energy industry.

In the current state of research, the aggregation and especially the weighting of different information is mostly compiled by expert opinion. This is a very important aspect when it comes to individual ratings for national economies or companies, addressing their specific needs, since the assessment of criticality always depends on the perspective from which it is conducted. However a quantitative approach on determining potential driving factors could help to confirm or to revise expert opinions on important indicators and their influence on different raw material markets.

Thus, while the exact definition of criticality depends on the respective field of application, in the following we assume that economic scarcity is at least one dimension of criticality, as every utilized commodity has to be bought for some price and large price fluctuations or increases constitute at least some degree of critical implications for companies as well as economies. While it is clear that this dimension is not sufficient to capture all aspects of criticality, we believe that definitions of criticality that do not incorporate economic scarcity are heavily restricted in their practical applicability.

Methodology

As we have seen the evaluation of raw material criticality is an extensive heterogeneous research area, which considers ecological, social, political and economic impacts of the usage of raw materials. However, when taking a closer look at all these perspectives almost all criticality studies are using supply risks and economic scarcity for their