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Measurement of mineral supply diversity and its importance in assessing risk and criticality

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ABSTRACT

The diversity of supply, or conversely its concentration, has become one of the key factors in measuring the criticality of minerals. The premise is that if supply is limited to just a few major suppliers the risk of supply disruption is increased, although in reality it depends on many more factors that can be complicated to measure. In addition, there is a wide range of possible methods for measuring supply diversity or concentration, some involving the use of complicated formulas, which can easily become bewildering to the non-statistician. Often the intricacies of their use, the data inputs and sources, and the resulting indices, are not fully understood with the consequent risk of misinformed decisions being based upon them. This paper examines a selection of the available indicators, discusses their limitations and illustrates how a simple index, such as concentration ratio, can be as informative as more complicated approaches. Further, it uses the trends in supply diversity for five minerals (fluorspar, lithium, coal, copper and nickel), taken at decadal intervals over the past century, to demonstrate that a snapshot index taken at a single point in time does not accurately determine whether the level of supply concentration is a cause for concern.

1. Introduction

The concept of raw materials 'criticality' is not new (see Glöser et al., 2015 for a useful summary, particularly of the 20th and 21st centuries) but it has become one of the most frequently discussed topics in recent times with, for example, the number of papers on the subject published in 2000–2011 more than treble that of 1990–1999 (Speirs et al., 2013). The dictionary definitions of the term 'criticality' state that these materials are those of "highest importance", which implies a usefulness that would make them almost essential. In recent years materials have been described as 'critical' usually because there is some perceived risk that they might become scarce or not routinely available for modern technology. Graedel et al. (2014) provide a useful introduction to the subject and describe some of the associated complexities.

A significant number of studies have been conducted to assess whether a range of metals or materials can be defined as 'critical', each using different sets of criteria and diverse methodologies (e.g. National Research Council, 2008; European Commission, 2010, 2014 and 2017; British Geological Survey, 2015; Graedel et al., 2015; Gemechu et al., 2015; McCullough and Nassar, 2017). However, one aspect that is common to all these studies is an assessment of 'supply risk' or the 'risk of supply disruption' and the assessment of this factor always includes some measure of 'supply concentration' (Speirs et al., 2013). The premise is that if the supply of a material is limited to a few countries the risk of supply disruption is increased, although in reality the situation is much more complicated than this.

The concentration of the supply of a material to a few countries can cause prices to rise or become more volatile as competition for the material increases and concerns grow about possible supply constraints (De Groot et al., 2012). Rising or volatile prices and concerns about supply restriction may also result in consuming industries seeking to make significant changes such as material substitution, redesign of products to use less of the material or increased use of alternative sources e.g. from recycled products (Graedel et al., 2014). These kinds of industrial changes can have serious consequences for costs and profitability (McLelland et al., 2014; Hendricks and Singhal, 2005). Some of the 'criticality' studies have attempted to incorporate market volatility into the assessment of whether a mineral is critical (e.g. McCullough and Nassar, 2017). There are also a number of actions that may be taken at government level such as funding research to improve processing technologies, supporting exploration or legislation aimed at improving recycling rates (Graedel et al., 2014).

Most of the 'criticality' studies that have been carried out should be considered as providing an 'early warning' of potential problems. The actual supply of materials is a complex web of interconnected companies and countries with a wide variety of influencing factors, which requires more detailed analysis if a full understanding of the system is

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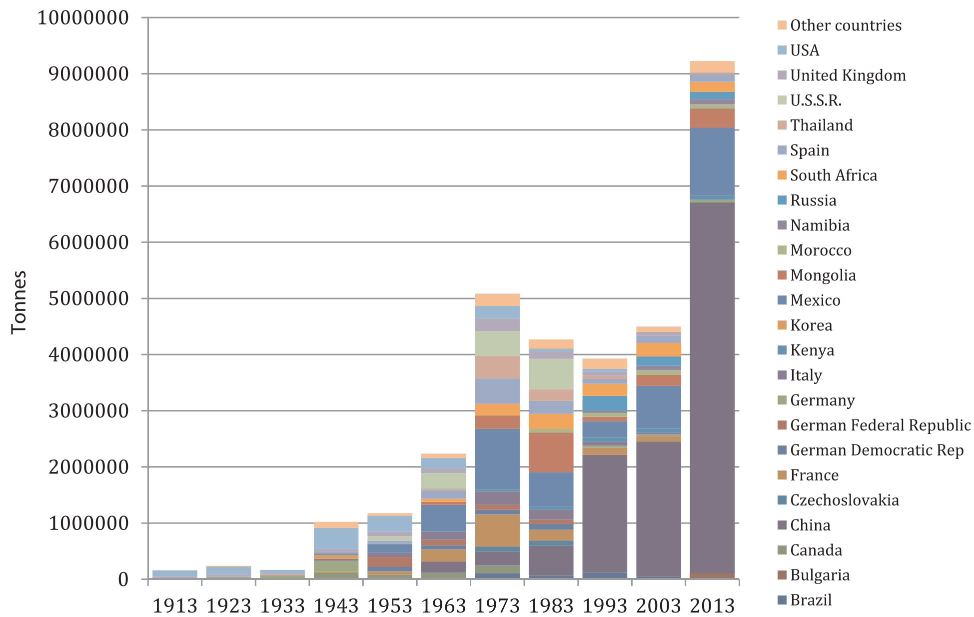

Fig. 1. Global production of fluorspar at decadal intervals from 1913 to 2013 (data from BGS, 2017).

to be obtained (McCullough and Nasser, 2017).

In the context of global studies 'production' is used a proxy for 'supply' and potential supply from stockpiles is ignored. For clarity, the term 'production concentration' is the direct opposite of 'production diversity' (Acar and Bhatnagar, 2003).

In many cases the measure used for 'production concentration' is the Hirschman-Herfindahl Index (HHI), which is described more fully later in this paper. But the use of HHI has its complexities and there are also other measures that can be used to make comparable assessments. Furthermore, it could be argued that it is not the production concentration itself that is the issue in determining a mineral's criticality but rather the potential geopolitical issues associated with the supply concentration. Statistical measures also exist that quantitatively measure dominance in a market and, as this paper demonstrates, these can also be applied on a global scale.

This paper uses a dataset from the British Geological Survey (BGS) known as "World Mineral Statistics" to examine the diversity or concentration of production for five mineral commodities: fluorspar, lithium, coal, copper and nickel. This dataset contains over 100 years of annualised production data by country and consequently enables the examination of how mineral supply diversity has changed over the last century. A range of established statistical measures are presented and compared in order to draw conclusions about their usefulness and usability in the context of mineral commodities.

The World Mineral Statistics dataset commenced with the publication of "The Mineral Industry of the British Empire and Foreign Countries, Statistical Summary (Production, Imports and Exports)" by the Imperial Mineral Resources Bureau in 1921 (IMRB, 1921). This first volume, containing statistics for 43 mineral commodities for the years 1913–1919 listed by country worldwide, was the direct result of supply restrictions incurred during the First World War. The Imperial War Conference of 1917 recommended the formation of the Bureau, which received a Royal Charter in 1919, expressly for the purpose of collecting and disseminating information relating to mineral resources for the benefit of defence and industry (Imperial War Conference, 1918).

Over the subsequent decades the annual publication incurred many changes, not least the removal of references to the "British Empire" and the somewhat disparaging "Foreign Countries" in the 1950s. Many countries have become unified, dissolved into constituent parts or adopted new names, reflecting 100 years of social and political change. The number of commodities covered by the dataset has increased such that recent volumes, now called "World Mineral Production", contain statistics for more than 70 mineral commodities (e.g. Brown et al., 2017). Metrication of units occurred in the early 1970s followed by the introduction of a storage database in the early 1990s and the digital dissemination of the statistics via an online archive in 2012 and data download tool in 2014.

Today, the World Mineral Statistics dataset continues to be maintained by the BGS and "World Mineral Production" is still published annually. The entire series of publications have been scanned and made available online and the statistics from 1970 onwards can be downloaded directly into MS Excel. The dataset itself is almost unique globally, with only the United States Geological Survey having one that is comparable in terms of the numbers of years encompassed.

2. Supply statistics

The five commodities discussed in this paper were selected on the basis that they would likely reveal different levels of production concentration. These include commodities where supply appears to have become more concentrated over time, with one producer believed to be dominant (fluorspar, lithium) and commodities for which supply appears to have become more diverse in recent years, albeit still with one notably large producer (coal, copper). Production of the fifth commodity (nickel) does not appear to be significantly concentrated in any single country. The data presented here are based on 'mine production' of these commodities (reported as metal content for lithium, copper and nickel) and are shown against the country in which they were extracted.

Due to the size of the dataset, sample intervals of 10 years have been used to display and assess how the output of producing countries have changed with time. It is assumed that these sample years are reflective of the entire decade from which they are taken, but these samples do not represent an amalgamation of the entire decade and it is possible that additional countries may have started and then ceased production in between the selected years. Countries producing smaller quantities of the commodity have been grouped as 'Other countries' in Figs. 1–5 to improve the clarity of the graphs. The data used to generate the graphs in this paper are available in the supplementary information (Tables S1 to S10) and, specifically, the total numbers of producing countries in any sample year are shown in Table S6.