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A dynamic perspective of the geopolitical supply risk of metals

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A B S T R A C T

Metals are distributed in the earth's crust in varying amounts and ore concentrations, implying that some countries have more metal resources than others. This inequality in geological resource distribution may lead to potential constraints and bottlenecks of a steady resource supply. In the context of strategic planning and innovation, and in scientific literature, this aspect is often referred to as *geopolitical supply risk*. In the past few decades, cobalt crisis, the oil embargo, and the more recent Rare Earth Elements (REEs) issue are the best examples regarding the geopolitical supply risk of mineral resources. The aim of this study is to present a historical overview of the development in geopolitical supply risk of 52 metals during the past two decades and to support an assessment of such risk in the future, i.e. 2050. A geographical mapping of metals primary production in 1994 and 2013 is included which shows a shift from developed economies to developing economies over this time period. Our analysis demonstrates that the geopolitical supply risk of metals has been fluctuating during the past two decades due to change in the number and production share of producing countries. During this time period, Chinese share of global metals production has increased from 23% to 44%. China, today, is also the dominant supplier of 34 metals, out of which 23 are considered as *critical resources* by the European Commission. The future geopolitical supply risk is less dependent on the present production distribution and more dependent on the location of current geological resources and the future discoveries, as well as on the technological development to improve profitability of mining the currently sub-economical resources.

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1. Introduction

The Modern society depends on metals. Metals are the basis of our infrastructure and the technology, without which it is hard to imagine modern life. Metals are non-renewable by nature as they have been generated as a result of geological events spanning over hundreds of millions of years, which makes them a finite resource. Nevertheless, metals do not disappear after their consumption *per se* like some other resources especially fuel minerals e.g. oil, gas and coal due to their non-dissipative nature. This means that metals can be reproduced by recycling them from urban mines, though with the product's long lifetimes and economic implications. Despite the fact that the geological resources of metals are finite, their unprecedented extraction from the earth especially during the last two centuries has raised concerns regarding their long-term availability to meet the demand of future generations (Bardi, 2014; Prior et al., 2012). Simultaneously, we have witnessed the substantial growth of economically viable geological reserves[1] of these metals over time, which has been made possible by the advent of modern technology making the once very expensive to mine lower ore grade resources to be exploited economically today (Habib and Wenzel, 2014). Within the context of secure, uninterrupted, and long-term availability of resources, a relatively new research field of *resource criticality assessment* got widespread popularity during the recent years (Habib and Wenzel, 2016).

A critical resource is considered to be one which is significantly important for the functioning of a system i.e. a technology, company, nation or the whole world, and at the same time is subject to high level of supply risk. Supply risk further can be assessed with the help of a number of constrained parameters or indicators, where the two most commonly used indicators are geological and geopolitical supply risk of a particular resource. *Geological supply*

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[1] According to the USGS, Reserve is that part of reserve base (part of the total geological resource of a metal) which could be extracted or produced economically at the point of determination (Source: http://minerals.usgs.gov/minerals/pubs/mcs/2009/mcsapp2009.pdf).

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risk is often represented with the help of reserve to production ratio, which shows the lifetime (number of years) of currently known reserves. Another important parameter of geological supply risk is the share of a resource produced as a by-product of some main product, e.g., molybdenum is mainly produced as a by-product of copper. This reflects the concern regarding market ability to meet a sudden increase in demand if the resource in question is mainly produced as a by-product (Habib, 2015).

In recent history, the nature of supply risk for metals has shifted from geological availability/scarcity to more geopolitical availability/scarcity. *Geopolitical supply risk* addresses the risk of potential supply disruptions caused by a single or few countries controlling the market of a particular metal and the level of political stability in such countries (Habib and Wenzel, 2016). The cobalt supply disruption in late 1970s, the palladium supply restriction in late 1990s, and the Rare Earth Elements (REEs) issue in 2010–2011 are good examples of geopolitical factor of metals supply risk. The detail of these resource disruptions is presented in the following section.

1.1. Resource supply disruptions from the 1970s until present

1.1.1. The cobalt supply disruption in the 1970s

The cobalt (Co) supply restriction in 1978 is a good example of the limited availability of a metal due to supply disruptions, and its consequences for society. Cobalt is a metal of strategic importance and is used in both industrial and defence related applications. The major uses of cobalt are superalloys which are further used in aircraft engines, magnets, cemented carbides, cutting tools and other chemical industry applications (Habib, 2015; Harper et al., 2012; USGS, 1999a). Cobalt has been identified as a critical resource to the European Union due to the concerns related to its supply risk and economic importance (European Commission, 2014, 2010).

During the early 1970s, the Democratic Republic of Congo (then called Zaire) and the neighbouring country Zambia were in control of almost two thirds of the global cobalt production. In 1978 there was political instability in the Democratic Republic of Congo which resulted in slowing down of mining activity. Meanwhile, the demand of cobalt increased sharply due to an upsurge in the global economy. Thus, the gap between demand and supply coupled with the delayed transport of cobalt from the producing countries to the Western world resulted in price speculation. The price of cobalt increased fivefold from \$11,880 Mg^{-1} in 1976 to \$55,000 Mg^{-1} in 1979 (Habib, 2015; Alonso, 2010).

The supply constraints of cobalt had a wide range of implications for the industry and governments. This forced the stakeholders to find solutions such as reducing the use of cobalt, finding substitutes in key applications, diversifying the primary supply by increasing production of cobalt in other countries, and building stockpiles for defence related uses. As a result of the crisis, the substitution possibility of cobalt was taken very seriously, which is visible from the decreased consumption of cobalt in permanent magnets which were significantly displaced by the newly developed ferrite magnets. The total consumption of cobalt for permanent magnets dropped from 30% before the crisis to 10% after the crisis (Wagner and Wellmer, 2009). Furthermore, the recovery of cobalt from the scrap superalloys doubled (Alonso, 2010; USGS, 1999a). The cobalt supply disruption demonstrated the importance of having a more diverse supply of resources instead of a near-monopoly situation, in order to minimize the implications of potential supply constraints for different stakeholders. For example, immediately after the cobalt crisis, Zambia and Australia increased the production of cobalt to reduce the dominance of the Democratic Republic of Congo over global primary supply. Further, it provided incentives to industry to increase the recovery rate of cobalt from the scrap material and, thus, reduce the dependence on primary supply. Moreover, the mining and refining companies improved their processes to reduce process losses and enhance the recovery of cobalt from its ores (Habib, 2015; Alonso, 2010).

1.1.2. The palladium supply disruption in the 1990s

Palladium (Pd) belongs to the precious metals group i.e. platinum group metals (PGMs), which are mainly used as catalysts in the automobile sector for pollution abatement. Other uses of PGMs are in fuel cells, petroleum refining, chemical industry, electronics, glass manufacturing, medical appliances, jewellery, and as investment (USGS, 2012a). The leading use of palladium is in automobile catalysts, which corresponded to almost 72% of total palladium consumption in 2013 (Cleantech VWS, 2014). In 1997, the U.S. Environmental Protection Agency's introduced and voluntarily implemented the National Low Emission Vehicle (NLEV) Program, which got federally mandated in 2001. This law emphasized lowering hydrocarbon emissions from the automobile sector, and thus enforced the use of catalytic converters to reduce emissions. This further led to an increased demand of palladium in catalytic converters for the gasoline-fuelled vehicles (Habib, 2015; USGS, 2012a).

During the late 1990s, a supply disruption of palladium was experienced, because Russia in 1997 reduced the exports of palladium by nearly 65%, while remaining the major producer with a 43% share of global production. Meanwhile the demand for palladium had skyrocketed within the automotive industry (38% annual growth) due to the enactment of NLEV program in the same year. The significant supply shortfall led to an enormous increase in the price of palladium from 1997 to 2000, which further resulted in dramatic changes in demand of palladium. The total demand of palladium in 2002 dropped by 50% compared to the demand in 1999. Even though the demand grew afterwards, it was still lower in 2007 compared to 1999 (Alonso, 2010; Johnson Matthey Precious Metals Management, 2008). Another response from the demand side was to diversify the supply by increasing the production capacity in other countries such as Canada, South Africa and Zimbabwe (Habib, 2015).

1.1.3. The rare earth elements supply disruption during the recent years

The most recent example of metals supply disruption is of REEs. The REEs group consists of lanthanide series consisting of 15 elements (atomic number 57–71) plus scandium (atomic number 21) and yttrium (atomic number 39) (Kirk-Othmer, 2005; Ulmanns, 2005). REEs have unique physical and chemical properties which make them highly attractive in many of today's high-tech applications e.g. permanent magnets containing neodymium and dysprosium. The performance level provided by these magnets in terms of their magnetic strength allows significant size and weight reduction in many of today's modern applications while maintaining the same performance level. These magnets are widely used in computers, audio systems, electric and hybrid vehicles, cell phones, wind turbines, Magnetic Resonance Imaging (MRI) machines, and others (Habib et al., 2014, 2015).

From 2005 to 2010, China has been the dominant producer with 97% share of the global REEs production. During the same period, the Chinese government kept shrinking the export quota of REEs to the rest of the world, where this quota had reduced by almost 53% from 2005 to 2011 with the most significant reduction from 2009 to 2010, which alarmed the industrial players and governments alike (Habib and Wenzel, 2014). China reduced the export of REEs to the rest of the world in order to prioritize the domestic demand and to

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