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Technological change and metal demand over time: What can we learn from the past?

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ABSTRACT

This paper contributes to the understanding of metal demand development over time by illustrating the impacts of different aspects of technological change using historical data. We provide a direct, quantitative comparison of relative change in global primary production for 30 metals over 21 years (1993–2013), capturing the range and variation of demand development for different metals within this period. The aspects of technological change contributing to this variation are investigated in more depth for nine metals. Demand for 15 of the 30 metals increased significantly more than GDP between 1993 and 2013. For five metals, demand in 2013 was about or more than 400% of their demand in 1993. All of these metals had a total primary production of < 100 kt in 2013. Concerning the metals under detailed investigation, comparatively high growth ($demand_{2013}$ > 500% $demand_{1993}$) could be attributed to emerging technologies in the case of indium and cobalt. Comparatively low growth ($demand_{2013}$ < 200% $demand_{1993}$) was due to substitution of a technology in case of silver and caused by improvements regarding material efficiency and recycling in case of tin, palladium and platinum.

1. Introduction

Metals are essential raw materials for both basic and advanced technologies. Consequently, ensuring a sufficient metal supply to meet demand is an economic necessity. At the same time, metal mining and processing is associated with environmental impacts [1]. For both reasons, future scenarios have become an established tool in decision guidance at national and international levels [2–6]. In order to focus political and industrial measures, it is necessary to estimate what developments in demand for different metals are possible and which of these developments need exceptional action. For the required future scenarios on metal demand, understanding the factors that drive demand development is crucial.

A variety of factors are known to influence metal demand, such as world population, disposable income, regulations, incentives, policy, trade regimes, etc. Concerning economic growth and changing consumer preferences [7–10], the intensity of use hypothesis [11, 12] defines the intensity of use as demanded material per unit of GDP. It postulates that the expansion of manufacturing and construction by industrialization causes the intensity of metal use to rise with GDP in low-income countries. In contrast, shifting preferences towards less material-intensive goods and services are assumed to counteract this increase, finally leading to decreasing intensity of use with increasing GDP [11, 12].

However, as Crowson [10] points out, the intensity of use hypothesis alone is not sufficient to explain development in material demand, as it neglects the influence of technological change. Among the different aspects of technological change, the emergence of new technologies has gained particular attention. Especially for the so-called technology metals (e.g. indium, germanium, gallium, rhenium, selenium or rare earths), an exceptional increment in demand due to emerging technologies is considered likely [2–6, 13].

In addition to the emergence of new technologies (including their invention, innovation and diffusion), continual improvement of technologies is a constitutive part of technological change [9]. Continual improvement of production technologies is generally connected with a decrease in costs (e.g. for labor, energy, material), which tends to make products less expensive and more accessible to consumers, possibly leading to higher overall demand. In the case of improved material efficiency, a decrease in metal demand could be expected but this may be counteracted or even overcompensated by increased demand for the (now cheaper) products—the so-called "rebound effect" [14]. Furthermore, technological change (in the shape of emerging technologies as well as continually improved technologies) also includes enhancements of recycling and other aspects of a circular economy, which lead to a reduced primary demand for materials. Finally, new technological

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developments do not necessarily mean their raw material requirements are additive to that of established applications. Instead, the introduction of new technologies can also result in the substitution of an established technology, possibly shifting raw material requirements to a different set of raw materials.

Consequently, technological change can have increasing effects on demand for some materials and, at the same time, decreasing effects for others. Therefore, a better understanding of the development of metal demand over time requires a combination of aspects of GDP growth, changes in consumer preferences and gradual as well as radical technological change.

This paper aims to contribute to the understanding of metal demand development over time by illustrating the impacts of different aspects of technological change using historic data on metal demand. While it is clear that past developments cannot simply be transferred or extrapolated to future estimations, learning as much as possible from the available knowledge of historic developments is an established approach in scenario-based analysis of future developments [15]. In this regard, we aim to contribute to the development and interpretation of future scenarios of metal demand by improving our basic understanding of historic developments.

For this purpose, we firstly provide a direct, quantitative comparison of relative change in global primary production for 30 metals over 21 years (1993–2013), which will show the range and variation of demand development for different metals within this period. In particular, we use the historic data to test the intuition that smaller markets and metals associated with "high-tech" applications are more prone to exhibit exceptional growth. Secondly, we analyze how demand changed for different applications between 1993 and 2013 for nine metals to investigate which aspects of technological change drive the variation in demand development for different metals. The nine metals selected show examples of the influence of a phase-out or substitution of a technology in decreasing demand for a certain metal, as well as of the effects of efforts regarding efficiency and recycling. Furthermore, the significance of change in demand due to emerging technologies in comparison to established technologies and its dependence on market size and specific demand for a metal for a certain emerging technology are illustrated. This aspect is further illustrated by a future scenario of demand for copper and lithium for electric cars.

2. Data and approach

The period 1993–2013 (21 years) was selected as the time frame of this study because it appears long enough to allow significant changes in demand for different metals due to technological change while at the same time having comparably good data availability. For this period, data of global primary production for 30 metals was collected. These data on raw material extraction from the lithosphere provide a first approximation to raw material demand—ignoring temporary stocks and recycling. They have the advantage of being readily available for a wide variety of raw materials and usually as time series for a number of years, provided by geological services. For this paper, primary production data as published by the U.S. Geological Survey [16, 17] was used for all metals except for lithium. Since global primary production of lithium in 1993 was not published by USGS, we rely on a personal communication from the Federal Institute for Geo-Sciences and Raw Materials (BGR/DERA) for production data in 1993 as well as 2013.

Data for demand by application for the selected nine metals was collected from metal institutes (ITRI, The Silver Institute, CDI), companies (Johnson Matthey), market analysts (Roskill) and geological services (BGR/DERA, USGS) [16–25].

To further illustrate the effect of a technological development on different raw materials markets, two scenarios for electric cars and their requirements of lithium and copper are presented in Section 4. Scenarios were taken from [26] and only the production data were updated for this paper.

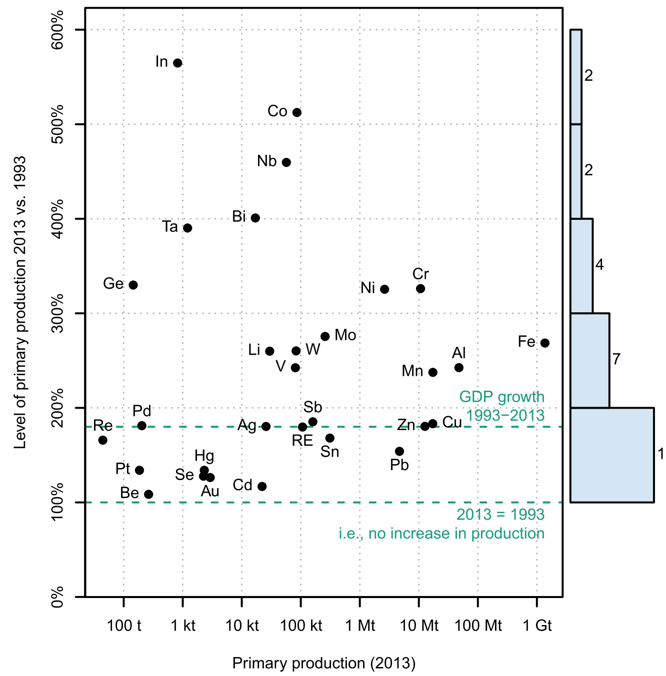

Fig. 1. Relative increase in primary production of various metals. Production data taken from [5]; GDP growth (constant 2010 US$) from [27]. Units: t = metric tons, kt = thousand metric tons, Mt = million metric tons, Gt = billion metric tons.

3. Results and discussion

3.1. Primary production of selected metals in 1993 and 2013

Fig. 1 shows the relative increase in global primary production of 30 metals between 1993 and 2013 as the ratio of $\text{demand}_{2013}/\text{demand}_{1993}$ on the y-axis versus the absolute tonnage of primary production in 2013 on the x-axis (cf. [5]). For comparison, economic growth (expressed as increase in GDP [27] in the same time period) is also shown.

Examination of Fig. 1 reveals that, while primary production for none of the metals has decreased, the degree of increase is largely variable: from essentially zero (Be) to more than 500% of the original level (In and Co) in the time period considered. The world economy grew to approximately 180% of the level in 1993 in the same time period [27]. Half of the metals (15 of the 30 metals considered) increased to less than 200% of their total production in 1993 by 2013. Therefore, they increased in a similar manner as GDP or less than GDP, i.e. their intensity of use is about or below 1. Note that this group comprises metals with a total primary production ranging from small (< 10 kt) over medium (< 1 Mt) to large (> 1 Mt) total size. The same is to be noticed for the 15 metals which experienced significantly stronger growth than GDP (intensity of use above 1). However, for all five metals having a ratio of $\text{demand}_{2013}/\text{demand}_{1993}$ of about or more than 400% (tantalum, bismuth, niobium, cobalt and indium), the total primary production is < 100 kt.

3.2. Demand by application for selected metals between 1993 and 2013

In order to analyze which factors connected with technological change were responsible for the large variation seen in Fig. 1, we selected nine metals covering a broad range of values in relative change in demand between 1993 and 2013 and having reasonably complete data series obtainable from published sources. Fig. 2 shows time series for the demand of In, Co, Li, Al, Co, Sn, Ag, Pt, and Pd. Note, however, that the figure is limited by data availability: While data for In, Al, Cu, Sn and Ag include demand satisfied both by primary and secondary sources (including both manufacturing and post-consumer scrap), the