An empirical analysis of structural forces

in refractory metal markets

von

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Executive summary

The record price development in commodity markets during the boom period lasting from early 2000 to mid 2008 highlighted a perceived scarcity particularly in metal markets that contrasted the preceding period beginning in the late 1970s of largely abundant availability and falling real metal prices.

While the fly ups in metal prices were most visible for exchange traded non-ferrous base metals, refractory metals used predominantly as alloys in the production of steel grades experienced an even stronger price rise. Whereas annual prices and production volume for non-ferrous metals rose by 12.2 percent and 4.9 percent respectively from 2001 to 2008, the aggregate price index for refractory metals rose by 17.6 percent annually, despite an average annual increase in the production volume of 9.6 percent.

Scholars are in disagreement how to evaluate the recent commodity boom with respect to its long-term impact on metal prices. Also, the primary focus of the discussion on metal markets and metal price development is based on insights derived from non-ferrous base metal markets. An in depth analysis of refractory metal markets matching the level of quantification found in works on non-ferrous base metals is missing.

The upward trend in demand for refractory metals ascribes to both an unprecedented surge in demand and to structural changes in the supply of alloyed materials. Contained only in traces in the end product, these invisible metals effectuate indispensable functions in steel grades, predominantly corrosion resistance, strength and high temperature strength. Driving the demand for these functions are long-term industry trends, which may be clustered as weight saving, advancement of operating parameters, quality improvement and operations in increasingly corrosive environments.

While these trends are not new, the surge in demand for sophisticated steel grades in developing countries to establish an adequate industrial infrastructure, a rising class of influential consumers in emerging economies, an increasing awareness for climate change and for a sustainable, efficient use of resources as well as constructions in increasingly corrosive environments such as the gulf region and polluted areas in emerging economies have all accelerated the demand for lighter and more enduring steel grades during the last decade. This development is reflected in the increasing intensity of refractory metals in steel not only in emerging but also in advanced economies during the commodity boom.

The solidity of these trends lends credence to the hypothesis that they will continue undeterred by the current economic crisis. Furthermore, the concentration of molybdenum and niobium in domestically produced steel in advanced economies is still higher by a factor of three compared to emerging ones. This implies that emerging economies, notably China as the dominant global steel producer have still a long way to come to catch up to advanced economies' levels. Both developments suggest solid demand growth for refractory metals going forward.

The growing economic relevance of refractory metals underlines the importance of a reliable and secure supply. Here, selected refractory metals have undergone a structural change in the composition of supply and are particularly exposed to induced scarcity situations and consequently price fly-ups and have become a weighty factor with respect to cost, risk, revenue and profit of hitherto unknown relevance.

Suppliers begin to reevaluate the significance of these metals in their portfolio and the revenue and profit opportunities that stem from it. Strong demand secures the profitability of developing hitherto uneconomic assets and introduces a new floor price as the cost position of the marginal producer rises and the tail of the cost curve becomes steeper.

Metal consuming industries, notably steel producers in countries relying on imports, are faced with a highly concentrated production profile in most refractory metal markets and are dependent on the willingness of exporters to trade. In this context, China's role deserves special mention. During the last decade, it has become a leading consumer of raw materials to sustain its economic growth. Yet its role on the supply side changed equally fundamental. It has become the largest exporter by far for many refractory metals, not only for those in which it holds domestic mining assets such as molybdenum but also for metals in which is has assumed a dominant position in the smelting and refining stage such as chromium.

China's determination to pursue its domestic interests over unobstructed trade has led to the introduction of export tariffs on raw and refined refractory metal to limit the unconstrained export of these metals in their intermediate forms and to nourish a downstream steel industry. The effect on China's role in the alloyed steel market is considerable. During the past decade, the country has switched from being a net importer to becoming a net exporter of alloyed steel, a trend, which correlates strongly with the increase in the intensity of advanced alloyed metals molybdenum and niobium in its domestic steel production. In parallel, exports of ferro-molybdenum, an intermediate product in which China held a dominant export position until 2003, have been replaced by alloyed steel exports containing molybdenum.

This indirect subsidy of downstream capacities in Chinese alloyed steel production has severe consequences for alloyed steel producers outside China reliant on imports of refractory metals in their intermediate forms. Their position is doubly inferior to their Chinese counterparts. Access to raw materials is restricted and average global raw material costs carry a surcharge of Chinese export tariffs. Furthermore, the competitiveness of their products outside their domestic markets, which are often protected by import tariffs, is challenged.

Changes in the global alloyed steel market during the last decade bear witness to the consequences of these distortions. Traditional exporters of alloyed steel, notably in Europe and Japan have lost significant market shares from the mid 1990s to 2008. The share of net alloyed steel exports of major Western European producers relative to total global alloyed steel exports fell from around 9 percent in 1994 to below 4 percent in 2008 measured by weight and to just above 5 percent measured by value. During the same period, Japan’s share of global alloyed steel exports dropped from around 11 to 8 percent measured by weight and to 6 percent measured by value.

Yet Sweden, Austria and Finland have managed to keep stable their share in global alloyed steel export markets. The business model of steel producers in these countries highlights a path to successfully stand the ground against global competition. Home to highly specialized steel producers, which is visible in the highest average concentration of refractory metals per ton of domestically produced steel in these countries, they are pursuing a strategy of innovation and specialization to maintain a competitive edge going forward.

The work intends to contribute to the discussion on the long-term impact of the commodity boom on metal prices. It enlarges the scope of metal markets in the focus of research to date by focusing particularly on refractory metal markets and illustrates through which forces structural changes in metal markets occur and how this may impact level and volatility of metal prices.

This approach complements existing metal price research by integrating industry insights and research findings in a framework to establish a holistic approach to price analysis. The approach chosen in this work owes to the author's practical industry background and focuses on the integration of solid industry knowledge. The insights gained are meant to contribute to prospective studies by scholars from various backgrounds and to the lively debate about the future development of metal prices.

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Table of abbreviations

ASSDA	Australian Stainless Steel Development Association
BRGM	Bureau de Recherches Géologiques et Minières
CDA	Cobalt Development Association
e.g.	Example given
f.	following
ff.	following (spanning more than one page)
GDP	Gross domestic product
Ibid.	Ibidem
IMnA	International Manganese Association
IMoA	International Molybdenum Association
ISSF	International Stainless Steel Forum
ITIA	International Tungsten Industry Association
ITRI	International Tin Research Institute
LME	London Metal Exchange
MCP	Material composition of product
PCI	Product composition of income
USGS	United States Geological Survey

1. Introduction

1.1 Problem definition and objective

The boom in commodity prices beginning in early 2000 and lasting till the second half of 2008 is widely thought to be unprecedented both in magnitude and duration compared to other price booms in the 20th century.[1] On the back of global GDP growing at an annualized rate of 4.4% between 2003 and 2008[2], commodity markets experienced unprecedented price hikes. Particularly the prices in metal markets showed record real price increases after decades of falling real prices[3]. The lack of availability of some metals highlighted an either real or perceived scarcity.

The unexpected price rally in metal markets took most market participants by surprise. After the high oil prices in 1973 and 1979 followed low growth and stagnation in mining commodities[4] affected by underinvestment in the development of new supply. Consequently, markets ran into supply shortages as established mining companies rushed to add capacity and faced constraints for key goods and logistics.[5] Financial markets faced additional risk to finance future exploration under increased economic and political uncertainty. At the same time, financial investors speculated increasingly on stock traded metals, further fueling short-term price spikes.

On the demand side, metal consuming companies, having enjoyed real falling prices[6] and largely free access to raw materials via trading on the global market for most of the two decades prior to the economic boom period, were unprepared for the severity of volatility and the increase in raw material costs. High, volatile prices, and a shortage in raw materials were the cause of uncertainty and threatened growth options and impeded additional investment.

The 2009 economic crisis put a sudden end to the raw material bonanza and prices for most metals markets plunged. New capacity expansion projects were put on hold or were

1 World Bank (2009), p. 51

2 International Monetary Fund (2009)

3 Compare chapter 2.2, Exhibit 2

4 Tilton (1985)

5 Pley/Rajagopaul/Rittner (2008), p. 21

6 Krautkraemer (1998), p.2080ff.

terminated as demand collapsed and mining companies scaled back capacity to preserve prices, cut costs and improve liquidity.

Such price instability is a common phenomenon in metal markets and metal prices are known to undergo pronounced cycles[7]. Because of short-term inelastic demand and capital intensive, inelastic supply, metal industries are characterized by periods of excess supply as well as excess demand causing frequent, volatile price changes. In this context, many analysts and scholars concur with the widely stated explanation that strong demand growth for metals and other commodities notably in China and to a lesser extent in India was a key driver for global supply constraints triggering the price boom[8].

Providing an outlook for future price development, leading mineral economists, while acknowledging the distinctiveness of the boom, withdraw to obvious statements such as that prices will be punctuated "as soon as new capacity is in place"[9]. A similar reasoning is expressed by TILTON/LAGOS who conclude that "With time, as happened historically, industry may reasonably be expected to construct new capacity eventually causing the price of copper to decline"[10], repeating the mantra of ever falling real metal prices, which some have observed throughout the last century[11].

Such reasoning may be premature as it ignores important developments in metal markets, which have been fueled by the commodity boom and which have lost none of their relevance in the face of the crisis. First of all, the above mentioned authors make no explicit assumption about the nature and cost structure of newly installed capacity, other than that once available it will end the price boom. However, this does not provide an answer to the obvious question, to which level prices will withdraw, nor which factors may influence a new price level. Nor are potential changes in the structure of the industry and their impact on metal prices addressed. Rather, RADETZKI et al. implicitly assume that no structural changes in metal markets have occurred and that the price boom in metals is only driven by a temporary surge in demand.

This perspective is questioned by several scholars. HUMPHREYS voices the hypothesis that prices may plateau at a new level rather than proceed in cycles.[12] HEAP suspects structural

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[7] World Bank (2009), p. 54. Compare also chapter 3.1.1

[8] World Bank (2009), p. 51; Radetzki (2006), p. 63

[9] Radetzki/ Eggert/ Lagos/ Lima/ Tilton (2008), p.125

[10] Tilton/Lagos (2007), p.22

[11] Tilton (1999), p.200

[12] Humphreys (2009), p.103; Humphreys (2010), p.11

changes on the supply side as a driver of the price boom and states that additional supply will come at higher cost.[13] JERRETT/ CUDDINGTON in their most recent analysis of the existence of super cycles in metal prices acknowledge that understanding the underlying factors behind the recent super cycle is "a high-priority task"[14], implicitly questioning that answers to this question can simply be deduced from earlier booms. Similarly, KRAUTKRAEMER argues against generalizations by emphasizing the need for a better understanding of unanticipated price changes on the basis of more detailed information tailored to individual metal industries.[15]

Secondly, the perceived scarcity during the boom has highlighted the importance of metals for the global economy, changed the perception of unconstrained availability of raw materials and brought the issue of resource security back on the agenda of major importers[16]. Whereas PORTER regarded domestic access to raw materials as a diminishing competitive edge due to the globalization of commodity markets in 1986,[17] it is an increasingly important factor again for companies competing globally as well as nationally. In their overview of mineral economics as an academic discipline, TILTON/GORDON give an implicit warning that the "the availability and security of at least their [consuming countries] nonenergy mineral supplies today […] could change, however"[18]. Market participants observe differences in price and availability of material between regions driven by trade restrictions constituting an either real or perceived competitive advantage for companies with preferential access to raw materials.[19]

In this context, the availability of minor metals, also called less common metals or spice metals[20] appears to be of particular concern. These metals, albeit used only in minuscule quantities in the end product, fulfill indispensable functional roles. Refractory metals, a sub-group, are used as alloying elements in steel. Other minor metals are vital parts of electronic components in modern products. While the importance of minor metals and of refractory metals in particular is often justified by their relevance in strategic applications, the overall economic relevance particularly of refractory metals has grown significantly during the

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13 Heap (2006), p.17

14 Jerrett/ Cuddington (2008), p.195

15 Krautkraemer (1998), p.2102f.

16 A search on the press search data base factiva for the key words "resource" and "security" rendered 19,261 hits in 2001 and 55,345 hits in 2008. Compare also chapter 2.2, Exhibit 3

17 Porter/Baldwin (1986), p.4

18 Gordon/Tilton (2008), p.10

19 Horninger (2008)

20 Reller et al. (2009), p.131

commodity boom[21], emphasizing a growing importance to the cost, risk, revenue and profit positions of market participants.[22] At the same time, fear of availability constraints is highest for minor metals due to an often highly regionalized supply structure.[23]

However, the markets for minor metals are largely excluded from economic analysis. Scholars analyzing the price, demand and supply economics of metal markets focus predominantly on iron and steel, the six non-ferrous base metals aluminum, copper, lead, nickel, tin, and zinc as well as well as three precious metals gold, silver, and platinum[24]. Consequently, the factors influencing the economic dynamics of minor metals are not fully understood and differences in market size as well as in the structure of supply and demand[25] prohibit a per se transferability of insights from non-ferrous base metal markets and demand a focused analysis of these markets.

In this context, the author wants to make additions to existing research on two main accounts. In order to expand the scope of economic analysis of metal markets, refractory metal markets are singled out of the heterogeneous group of minor metals as the most important sub-group from an economic standpoint. Their demand, supply, and market structure are distinguished from non-ferrous base metal markets and demand development before and during the commodity boom period is analyzed.

Furthermore, to enrich the discussion on structural changes in metal prices, a framework is defined that integrates the relevant structural forces impacting level and volatility of metal prices. Specific differences between refractory and non-ferrous base metal markets along the framework's structural dimensions are highlighted and the framework is applied to a refractory metal market to provide an example for the occurrence of structural changes in a metal market and illustrate the corresponding impact on the price.

Specifically, the following steps are conducted. The distinctiveness of the boom in metal prices is emphasized and the rising economic importance of refractory metals during this time period is quantified. Drawing on existing research from mineral economists and experts of

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[21] Compare chapter 2.3

[22] Langhammer/Zeumer (2010), p.21

[23] Bundesverband der Deutschen Industrie (2006), p.47f. A EU report classifies niobium, vanadium, chromite, manganese, tantalum, and vanadium as critical. EU (2008), p.17. The French geological survey Bureau de Recherches Géologiques et Minières (BRGM) identifies 16 minor metals as carrying a short to medium risks to their supply: antimony, chromite, cobalt, germanium, gallium, indium, lithium, magnesium, molybdenum, platinum, palladium, rhodium, rare earths, rhenium, titanium, and tungsten. Dechamps et al. (2002); Hocquard/ Samama (2006); Hocquard (2008)

[24] Compare chapter 3

[25] Compare Chapter 5

metal industries, a perspective on the coverage of metal markets in literature as well as on underlying structural drivers of metal prices is developed. Research gaps are then deduced with respect to the insufficient coverage of refractory metal markets and the lack of an integrated approach to capture the relevant structural forces that impact the level and volatility of metal prices. Subsequently, distinctions between refractory metal markets and non-ferrous metal markets on the demand and supply side are stressed to justify a separate analysis of the former. The distinct demand structure of refractory metals used predominantly as alloying elements in steel is disaggregated and traced back to the functions individual metals effectuate in steel. Growth of apparent consumption is then decomposed based on the concept of the intensity of use technique to quantify the influence of a metal's individual functional profile on its demand development. Furthermore, alloyed steel trade as a major channel for hidden imports and exports of refractory metals is examined. An investigation of further trends specific to individual refractory metal markets complements the analysis of refractory metal demand.

In a next step, conclusions are combined in an integrated framework to capture the structural forces that influence the long-term level and volatility of metal prices along four relevant structural forces. Characteristics within these forces distinctive to refractory metals are emphasized. This framework is then applied to the molybdenum market to shed light on structural changes in this market influencing the long-term price level and volatility as a consequence of the commodity boom. Finally, implications for scholars and market participants are drawn and recommendations for further research are suggested.

In differentiation to existing research and from the perspective of a practitioner, the author intends to address the underrepresented role of refractory metals in literature and to identify and consolidate the major structural forces that impact the level and volatility of metal prices. In particular, answers to the following research questions are sought:

What are distinguishing elements of non-ferrous base metal markets and refractory metal markets that justify a separate examination of the latter?

How does the distinct demand structure of refractory metals influence the demand development of such metals?

How can the impact of influences related to the demand structure of refractory metals be quantified and which other factors influence refractory metal demand?

What are the structural forces in a metal market that impact the long-term level and volatility of a metal price and which characteristics within these forces are specific to refractory metal markets?

1.2 Structure

After describing the problem definition and objective of this work in Chapter 1.1 the author will lay out its structure and next steps.

In chapter 2 the situation with regards to the extraordinary metal price development during the recent commodity boom between 2001 and 2008 is illustrated and the rising importance of refractory metals is stressed. Chapter 2.1 provides a categorization of metals into aggregate groups and classifies the group of minor metals and the sub-group of refractory metals. The distinctiveness of the recent price rally in metal commodities is covered in chapter 2.2. In chapter 2.3, the rising economic importance of refractory metals is quantified. Chapter 2.4 summarizes insights and implications.

In chapter 3, existing research is reviewed, research gaps are deduced and research questions defined. Chapter 3.1 is concerned with literature analyzing metal prices and the relevant underlying market forces identified to impact price level and volatility. Chapters 3.2 and 3.3 are concerned with a review of literature on demand and supply of metal markets to gain an overview of relevant forces identified to impact metal prices, assess the coverage of refractory metal markets, and review methodologies to analyze refractory metal demand. In chapter 3.4, research gaps are deduced and research questions are devised.

In chapter 4, approaches to analyze metal markets are evaluated. Furthermore, data sources and data preparation are critically discussed and metal markets for quantitative analysis selected. In chapter 4.1, methodologies and concepts to analyzing metal demand are evaluated and the choice of the intensity of use concept in this work justified. Additionally, structural forces on the metal supply side are deduced based on reviewed literature. In chapter 4.2 sources of raw data on refractory metal markets as well as necessary assumptions and simplifications for the preparation of data are critically discussed. In chapter 4.3, four decision criteria to select refractory metal markets for further quantitative analysis in this work are presented and refractory metals are evaluated accordingly.

Chapter 5 is concerned with the comparison of non-ferrous base metals and refractory metals. Structural supply side differences between the two groups of metals are discussed in chapter 5.1, differences in the structure and development of demand are illustrated in chapter 5.2.

In chapter 6, the demand development of refractory metals is analyzed. The relevance of a metal's individual functional profile it brings to bear as an alloy in steel is elaborated and linked to major industry and consumer trends (chapter 6.1). In chapter 6.2, the quantitative analysis of apparent consumption growth is prepared and a concept suggested to cluster the economies in the focus of this work. The subsequent chapters 6.3, 6.4, 6.5, and 6.6 are concerned with the decomposition of growth of apparent consumption of chromium, manganese, molybdenum, and niobium. In chapter 6.7 the influence of alloyed steel trade on the concentration level of refractory metals in domestic steel production is demonstrated. A perspective on micro trends within individual metal markets in chapter 6.8 complements preceding analyses. A summary and conclusions are provided in chapter 6.9.

In chapter 7, a framework is developed integrating major structural forces that impact the long-term price level and volatility of metal prices. Within these forces, characteristics of refractory and non-ferrous base metal markets are differentiated (chapter 7.1). Subsequently, the framework is applied to the molybdenum market to illustrate its applicability as well as the structural changes occurring as a consequence of the boom period (chapter 7.2).

Chapter 8 serves to summarize findings and develop conclusions and recommendations. In chapter 8.1, findings of this work are summarized along the research questions deduced earlier. In chapter 8.2, implications for further research are deduced and restrictions of this work critically assessed. Chapter 8.3 contains implications for practitioners.

2. Situation background

The following chapter provides background information regarding the categorization of metals (chapter 2.1) and the distinctiveness of the commodity price boom since early 2000 lasting till mid 2008 in the context of historical price development (chapter 2.2). Chapter 2.3 provides an approach to quantify the growing economic importance of refractory metals In chapter 2.4 findings are summarized.

2.1 Categorization of metals

The term non-ferrous base metals, precious metals and minor metals describe aggregate groups of metals. Metals are categorized in the wider context of mineral materials as illustrated in Exhibit 1. They are classified as non-energy minerals and usually split into four groups: iron ore, non-ferrous base metals aluminum, copper, lead, nickel, tin, and zinc, the three precious metals gold, silver and platinum group metals comprising iridium, osmium, palladium, platinum, rhodium, and ruthenium, and minor metals, also called less common or spice metals, the latter term reflecting the small quantities but essential functions these metals effectuate in the end product. Minor metals are further categorized as refractory metals, which are predominantly used as alloying elements in steel and other minor metals, for which a growing use in electronic applications is observed[26].

[26] Bilow/ Reller (2009), p.647f.

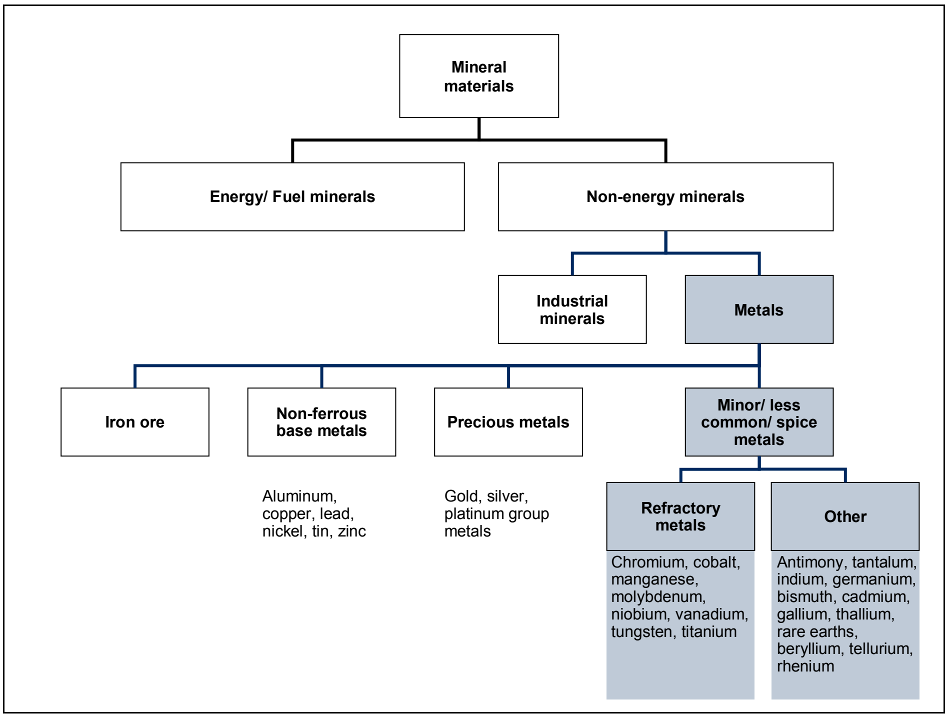

Exhibit 1 – Classification of minor metals

Source: Own illustration[27]

As the group of minor metals is the most diverse comprising over twenty metals[28], an individual analysis of all markets of these metals is beyond the scope of this work. Given the individual market forces influencing each market, any general conclusions relating to this group of metals have to be drawn with care, considering the wide range of markets included.

2.2 Distinctiveness of the commodity price boom since 2000

Scholars and practitioners are in agreement that the price rally in commodities lasting till early 2008 was distinctively different from earlier booms both in terms of magnitude and duration. According to a World Bank report, the boom in non-energy commodities was "the largest and longest of any boom since 1900"[29], dating its beginning around 2003. Scholars investigating the cyclicality of metal prices concur that the boom should be classified

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[27] Following Bundesverband der Deutschen Industrie (2006), p. 22f. Some elements such as magnesium and titanium are classified as industrial minerals as well as metals depending on the refined form.

[28] Rare Earths is here counted as one metal group but comprises 18 elements: cerium, dysprosium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, neodymium, praseodymium, samarium, terbium, thulium, ytterbium, yttrium, ferrocerium, monazite, and bastnasite

[29] World Bank (2009), p.51

as a new super cycle with a complete cycle length, i.e. price rise and slump, between 20 and 70 years[30] as opposed to a mere business cycle with a complete cycle length between 1 to 2 years and below 8 years[31]. HEAP defines super cycles as "a prolonged (decade or more) trend rise in real commodity prices, driven by urbanization and industrialization of a major economy".[32] JERRET/ CUDDINGTON suggest that there have been three previous super cycles and observe that "the most recent SC [super cycle] in all metal prices begins sometime between 1995 and 2000."[33]

RADETZKI analyzing commodity price indices also comprising a metal index identifies only three commodity booms and estimates that the third began in 2002. Coming from a practitioner's perspective, HEAP analyzes non-ferrous base metal prices and agrees with RADETZKI and JERRET/CUDDINGTON that the beginning of the new millennium marks the beginning of a new super cycle.

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30 Jerret/Cuddington (2008), p. 188

31 Roberts (2009), p.93 sets the minimum length for expansion and contraction periods at 6 months, i.e. 1 year for one complete cycle. Jerret/Cuddington (2008), p. 190 range business cycles from 2 to 8 years

32 Heap (2006), p. 2

33 Jerett/Cuddington (2008), p. 194

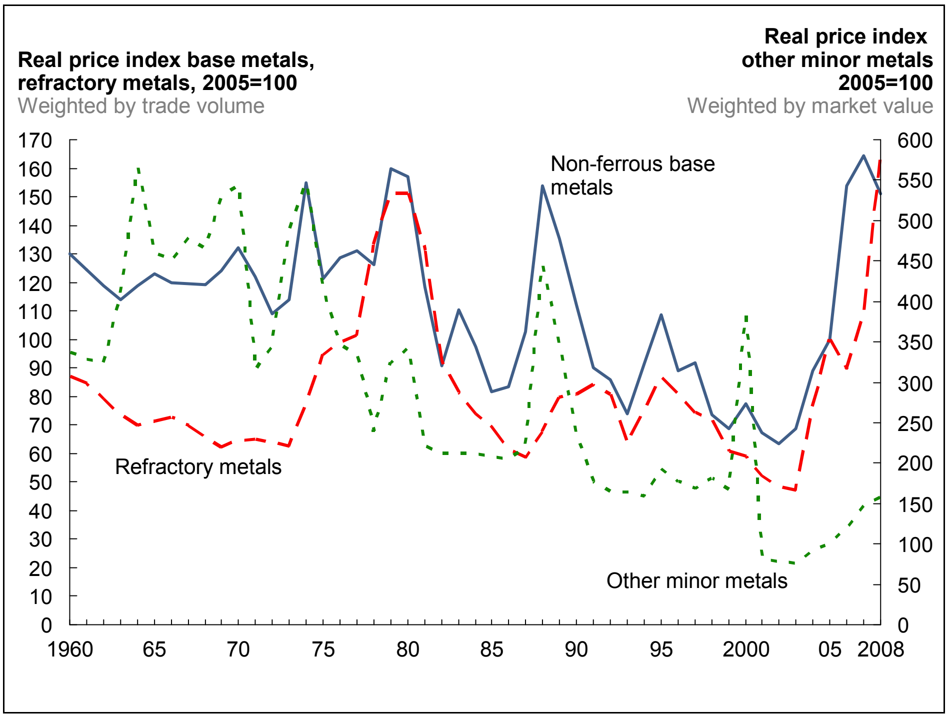

Exhibit 2 – Real metal price development by metal category[34]

Source: Own illustration

Exhibit 2 displays the indexed real price development of non-ferrous base metals, refractory metals and other minor metals between 1960 to 2008. The indices for the non-ferrous base metals and refractory metals are weighted according to their trade value[35]. For other minor metals reliable global trade data were not available and therefore the price series are weighted by their market value.[36]

By visual inspection of data, the perception of above mentioned authors regarding the distinction of the most recent price boom in non-ferrous base metals can be confirmed. From 2001 to 2008, the real price index for this aggregate metal group (solid curve) rose by an annualized 12.2 percent, surpassing previous real price records. This boom in metal prices

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34 Prices are based on USGS reported prices. Prices are deflated by GDP deflator, 2000 = 100. The index for other minor metals excludes prices for lithium and tellurium and from 1960 to 1991 excludes the reference price for rare earths. Compare Appendix, chapter 9.2 for details

35 The weighting factor of each metal is based on the metal's average 2002 to 2004 trade value relative to the total trade value of the respective metal group to which the metal belongs in accordance with IMF methodology

36 Compare Appendix for details and chapter 4.2 for data sources

was preceded by a period of overall long-term falling prices[37]. Between 1980 and 2001, the price index for non-ferrous base metals fell by 3.9 percent annually.

A slightly different picture emerges when inspecting the price development of refractory metals (dashed red line). The refractory metal index appears to track the non-ferrous base metals index since early 1970s, but the real price increase during the boom exceeds that of non-ferrous base metals. From 2001 to 2008, the annualized price increase of refractory metals was 17.6 percent. The period of falling prices after late 1970s is also more pronounced than for the non-ferrous metal index. Refractory metal prices fell by an annualized 4.9 percent between 1980 and 2002.

Finally, the price index for other minor metals (dotted line) displays an overall falling trend since 1960 interrupted by pronounced yet short-term price spikes. The price increase during the boom remained below that of other metal groups with an annual growth rate of 9.8 percent from 2001 to 2008. Between 1980 and 2001, price fell by 6.6 percent per annum.

The period of long-term falling prices preceding the boom is thought to have created the conditions for the following price development. It effectuated supply shortages as investment into new capacity was deterred.[38] When prices picked up, mining companies were quick to bring on line mothballed capacity but ran into supply shortages for key goods and logistics[39].

The introduction of export restrictions on metals notably by China as a major exporter of metal commodities in reaction to tightening resource availability further fuelled the price rally and sparked fear of resource security both among policy makers, companies dependent on imports and in the general public (Exhibit 3):

[37] World Bank (2009), p. 51

[38] World Bank (2009), p.52

[39] Pley/Rajagopaul/Rittner (2008), p. 21

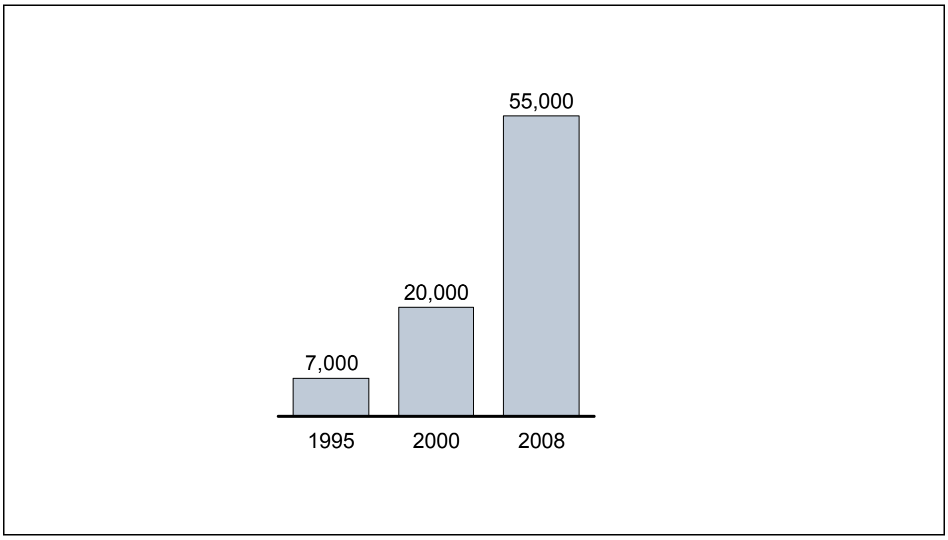

Exhibit 3 – Hits of words "resource" and "security" in press

Source: Own illustration[40]

A press-clipping research for the combination of the words "resource" and "security" in the factiva press database yielded 7,000 hits in 1995 and 55,000 hits in 2008, illustrating the rising attention the topic received.

The WTO does not prohibit such export restrictions provided that they are applied non-discriminatorily[41] and while not uncommon in other commodities, such as food[42] and non-mineral raw materials[43], in the past they have rarely been applied to metal commodities. The reason for this may be twofold:

- During the long-term period of falling metal prices and an overall abundant supply of metal raw materials, such tariffs would have made exports less competitive on a global market and burdened domestic downstream industries with potentially higher raw material cost.
- Export tariffs divert domestic production volume away from the global market to domestic industries. For countries with only a small share of global trade, export tariffs harm the competitive position as importers are able to turn to other exporters, compensating the higher raw material costs. Major metal exporting countries in the past

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[40] Factiva (2009). Based on search in media classified "All English speaking publications".

[41] Piermartini (2004), p.2

[42] Nogués (2008)

[43] Tykkylainen/Lehtonen (2008)

rarely had a domestic market able to absorb quantities large enough to generate an impact on the global market and often rely heavily on raw material exports to buttress government revenues.

This is changing with the rise of China. China's role in the metal commodity boom is widely identified as the major source of surging demand driven by industrialization and urbanization.[44] However, its role on the supply side is less well understood. China's rise as a major consumer of metals and other commodities was preceded by China's rise as a growing global supplier of metals. In a tightening market for raw materials, the introduction of export restrictions generally serves several goals[45]:

- Shielding the domestic markets from higher raw material cost
- Nourishing a domestic manufacturing industry: As exports restrictions do not apply to finished products, export restrictions give Chinese manufacturers a raw material cost advantage over foreign manufacturers. Overall, export restrictions lead to distortions in the efficiency of production as it encourages inefficient producers in the exporting country and discourages efficient ones in the importing country. [46]
- Buttressing government revenues
- Preserving domestic assets

Such policy action by a major metal exporter is unprecedented and no other significant exporter except Russia on a much smaller scale and India for chromite ore followed this example.[47]. Whereas export tariffs increase the cost of raw materials for foreign producers at times of already high prices, export quotas seriously impede the availability of supply as exports quotas set a definite limit to the volume available regardless of the price the importer is willing to pay.

As a reaction to tightening markets, a growing perception of resource scarcity and increasing export restrictions by China, three large importers took policy actions to target resource security:

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[44] World Bank (2009), p. 55; Pley/Rajagopaul/Rittner (2008), p. 21

[45] Barfield (2008), Nogués (2008), p.2

[46] Piermartini (2004), p.4

[47] United States Geological Survey reports a temporary ban of cobalt concentrates in 2008 issued by the government of Congo, the leading producer of cobalt. USGS (2008zo)

- In November 2008, the European Commission launched a new integrated raw material strategy to secure and improve access to raw materials for EU industry.[48]
- The Japanese Ministry of Economy, Trade and Industry (METI) initiated metal specific policies in 2007. In the case of tungsten this includes assistance in the development of new mines abroad, increase of recycling rates and promotion of research for substitutes.[49]
- In June 2009, the US and the EU jointly filed a WTO suit against China over export restrictions on certain industrial raw materials.[50]

The outcome and the impact of these counter actions are pending at the time of writing not least because the current economic crisis has lessened tension on metal markets for now and diverted attention to more urgent topics. In any case, the extraordinary length and duration of the metal price boom is rooted in physical supply constraints resulting both from a long period of underinvestment as well as government measures distorting global markets.

The economic crisis following the boom in commodities punctuated the price rally in commodities. Prices plunged in early 2009 or already in 2008 and demand for metals shrank across all markets. Companies put on hold or cut back investments to expand capacity of existing mines and to develop new assets in an effort to reduce costs and to address liquidity shortages. In some cases, far reaching decisions were made to abandon new projects and to merge with or to acquire competitors.

Yet, two developments stand out, which raise doubt that this boom has indeed come to an end. Demand from China, the engine for growth in metal commodities during the boom, which prior to the crisis was thought by some to be driven mainly by exporting activities[51] turned out to be surprisingly robust, lending credence to HEAP's claim that Chinese demand growth is fueled mainly by domestic demand[52].

Also, prices, albeit plummeting from record heights, are still above their real historical averages in some metal markets. This is illustrated for selected metal markets in Exhibit 4:

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48 EU (2009)

49 USGS (2007f), p.4

50 Euractiv (2009)

51 Radetzki (2006), p.63

52 Heap (2005), p.2

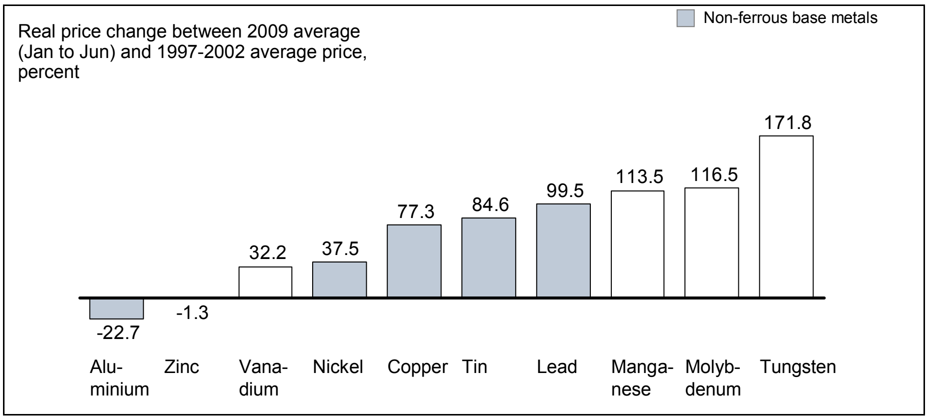

Exhibit 4 – Price change before and after price boom

Source: Own illustration[53]

Despite experiencing one of the worst economic crises in history and a major drop in metal demand, prices in some metal markets appeared to remain above their historical average in the first half of 2009 as illustrated in Exhibit 4. While aluminum and zinc dropped below their pre-boom average, nickel, copper, tin and lead stabilized noticeably above their pre-boom average. This development was even more distinct for selected refractory metals. Manganese, molybdenum and tungsten prices were more than double their historical average in the first six months of 2009.

2.3 Rising economic importance of refractory metals

The latest metal price boom beginning in early 2000 illustrated in Exhibit 2 was accompanied by strong growth in production volume. Between 2001 and 2008, cumulated production volume grew by an annualized 4.9 percent for non-ferrous metals and 3.4 percent for other minor metals. Output for refractory metals grew at an annual rate of 9.6 percent; double that of non-ferrous base metals as illustrated in Exhibit 5:

[53] 2009 price data from IMF (non-ferrous base metals) and InfoMine.com

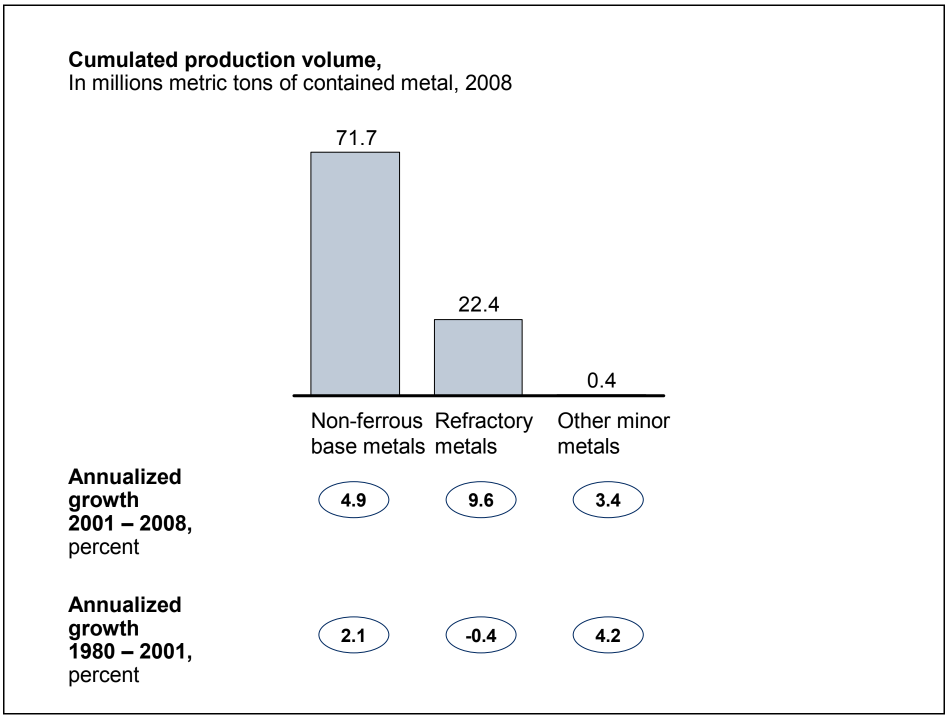

Exhibit 5 – Cumulated metal production in 2008

Source: Own illustration

Just as metal prices experienced a long period of stagnation prior to this boom, production volume also grew at a much slower rate between 1980 and 2001. Production volume for non-ferrous base metals grew at an annualized rate of 2.1 percent. Production volume for non-ferrous base metals stagnated on average over two decades. Other minor metals expanded by 4.2 percent during the same period.

Despite the stronger production growth of refractory metals, aggregated production volume of non-ferrous base metals in 2008 dominated refractory metal volume by a factor of 3.2 and other minor metals by a factor of 200. In order to assess the rising economic relevance of metals for consumers, it is necessary to capture how the amount spent for metals develops over time. The price of a metal reflects its opportunity cost, in the sense of what a consumer has to give up in order to purchase another unit of a metal.[54] A rising price indicates that a consumer has to give up more, if he is to obtain another unit of the metal. Whether the consumer indeed purchases another unit is measured by the consumption development. Multiplying global production volume V_i of metal i measured in metal content as an approximation of global consumption with the price P_i of metal i yields the absolute amount

[54] Tilton (2003), p.28; Tilton/Lagos (2007), p.20

spent on the metal, which may also be interpreted as the metal's market value, the revenue related to or consumer spending for the metal. Aggregating the market value of all metals in the aggregate metal group j denotes the market value of the aggregate metal group:

$$\sum_{i=1}^{n} MV_{ij} = \sum_{i=1}^{n} P_{ij} \cdot V_{ij} \cdot c_{ij} \quad (1)$$

c_{ij} is a conversion factor. If the unit price of the metal refers to the pure metal $c_{ij} = 1$. If the unit price refers to a processed form of the metal, e.g., a concentrate or oxide, which contains only a portion of the metal, $c_{ij} = \frac{1}{s_{ij}}$ $s_{ij} < 1$, with s_{ij} denoting the metal content in the processed form.

It should be noted that calculating the market value by taking the price of the pure metal implicitly assumes that all the metal produced can be valued according to this price. Whereas non-ferrous base metals are mostly traded in this form, refractory metals are often traded in the form of ferro-alloys or concentrates and only a small amount is refined further and sold as pure metal. Ideally, all forms of processed metal should therefore be valued by their respective market price. Most of the time price information is not available in such granularity. However, the published price of a metal is usually the price of the metal in the most commonly traded form. This listed price is usually a reference price for other processed forms. By evaluating the relative change of market value based on this reference price rather than the absolute level, the margin of error is reduced.

Also, aggregating the individual market values obscures differences between metal markets. General statements based on the market value development of the aggregate metal group must therefore be interpreted with consideration for the individual metal markets. Nonetheless, given the large amount of metals, an aggregated view helps to develop a first focus in the context of a top down approach, followed by a metal specific assessment. Finally, approximating consumption by global primary production neglects secondary production from recycled scrap, which implies that the absolute market value may be higher. However, the effect from omitting secondary production on the relative change of market value during a time period is assumed to be small.

Having these caveats in mind, developing a perspective on metal markets by assessing their market value yields important insights. Exhibit 6 depicts the growth rates in market value of aggregated metal groups before and during the boom based on three-year moving averages to receive more stable results. For reasons of simplicity, the periods are referred to as 1980 to

2001 and 2001 to 2008 in the text and in the exhibit caption to illustrate the span of years covered.

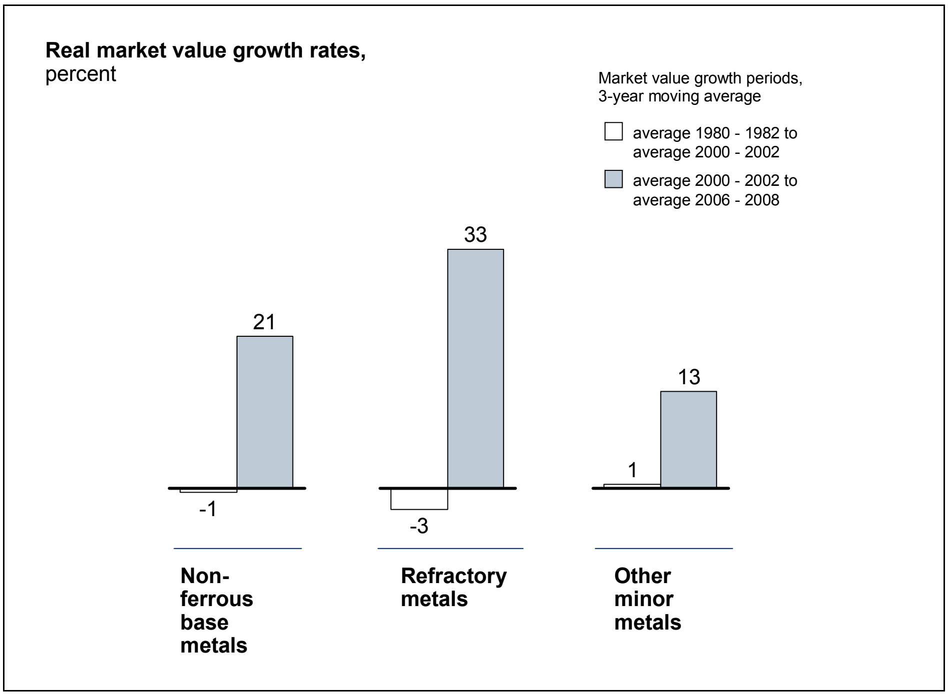

Exhibit 6 – Real market value growth by metal group before and during the commodity boom

Source: Own illustration

It is apparent that for the two decades prior to the commodity boom, real market value growth was stagnant or slightly negative across all metal groups, reflecting falling real prices and low production growth. However, during the boom from 2001 to 2008, rising real prices and a significant increase in production yielded higher growth rates of market value. Particularly the growth of refractory metals dwarfed that of other metal groups. Annualized growth in market value was 33 percent for refractory metals, compared to 21 percent for non-ferrous base metals and 13 percent for other minor metals. In other words, the absolute amount consumer spent for refractory metals rose faster by a factor of 1.5 annually compared to that for non-ferrous base metals. After a period of seven years at the end of the boom, consumers spent on average 2.4 times more on other minor metals, 3.8 times more on non-ferrous base metals and 7.2 times more on refractory base metals compared to spending at the beginning of the boom.

Exhibit 7 to Exhibit 9 show the market value growth for individual metal markets and the decomposition[55] into the respective value drivers real price and production as an approximation of consumption for the period 2001 to 2008.

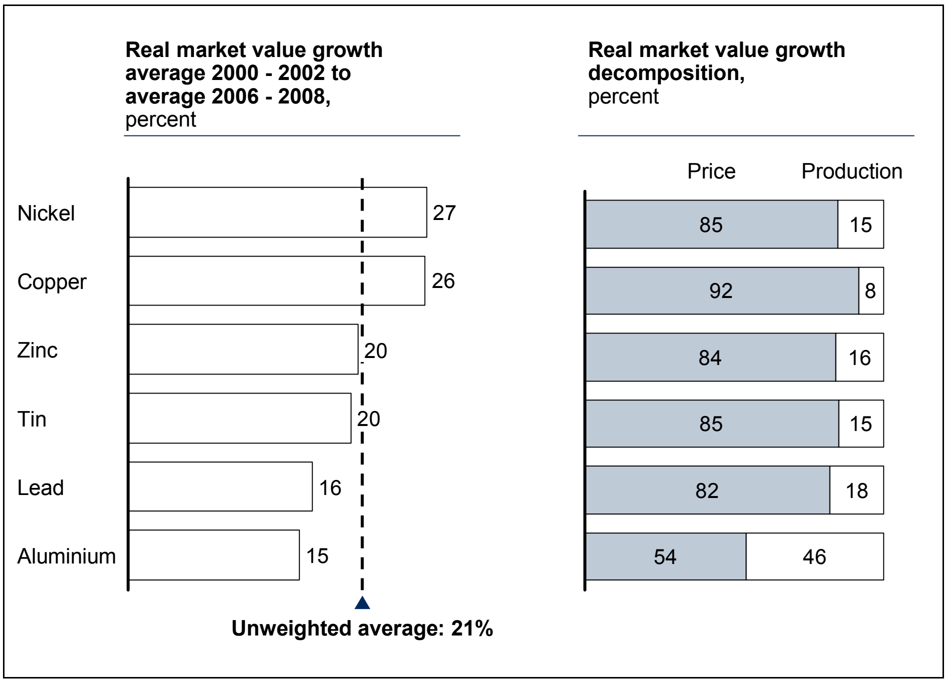

Exhibit 7 – Growth and decomposition of non-ferrous base metals market value from 2001 to 2008

Source: Own illustration

[55] The decomposition of market value growth is estimated keeping either growth (or decline) in production or price zero and calculating the market value growth had only one of the factors occurred. The percentage share of each driver was then calculated based on its portion of the actual market value growth. Because the product, not the sum of production and price determines the market value, a residual remains due to multiplicative effects, which was attributed to production and price based on the respective share of growth.

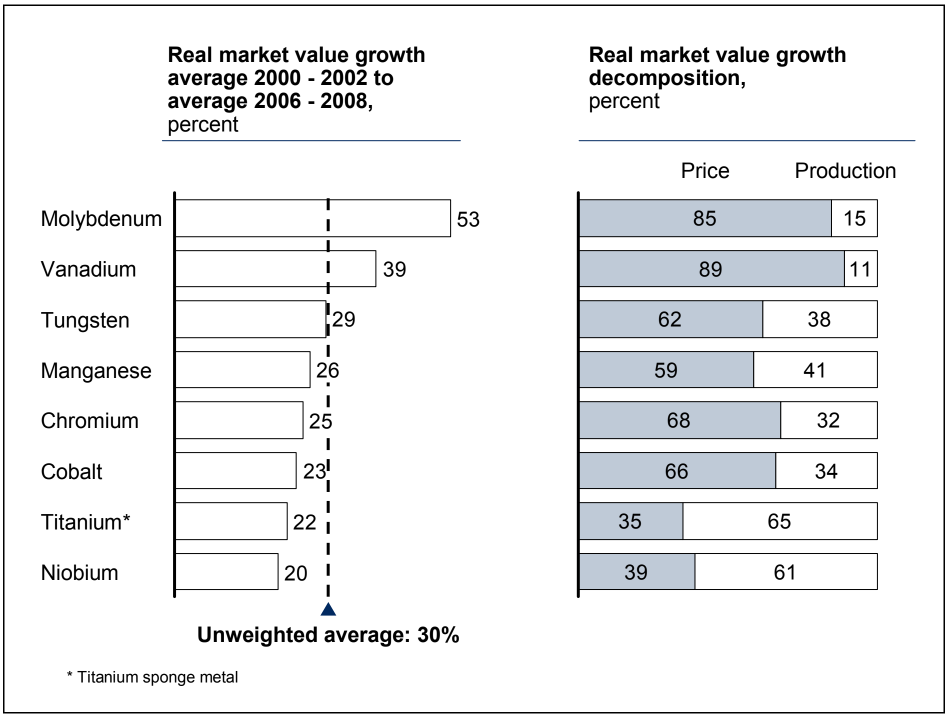

Exhibit 8 - Growth and decomposition of refractory metals market value from 2001 to 2008

Source: Own illustration

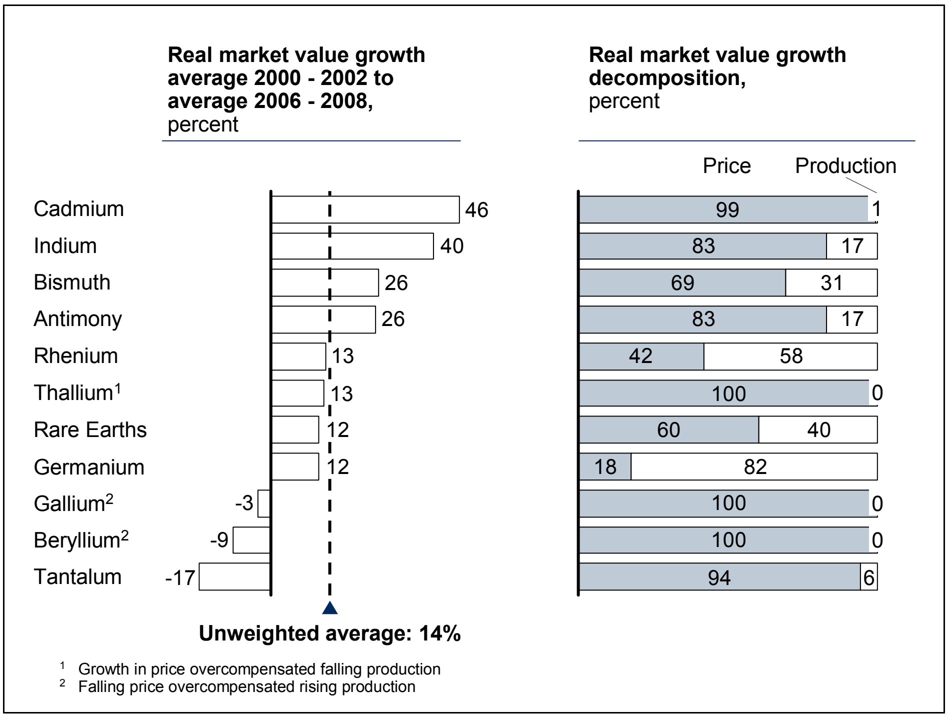

Exhibit 9 - Growth and decomposition of other minor metals market value from 2001 to 2008

Source: Own illustration

The market value growth rates of non-ferrous metals span a range of 15 percent for aluminum to 27 percent for nickel. The increase in market value from 2001 to 2008 was predominantly driven by an increase in real price across all metal markets, attributing over 80 percent to total growth. The exception was aluminum, were market value growth resulted equally from growth in production and real price.

A mixed picture exists for refractory metals. Growth rates for market value range from 20 percent for niobium to over 50 percent for molybdenum. For molybdenum and vanadium, an increase in real price was the major driver, contributing over 85 percent of market value growth. The dominant share of real price increase holds true as well for tungsten, manganese, chromium, and cobalt, albeit to a lesser extent. For titanium and niobium, an increase in market value stemmed to over 60 percent from a rise in production. On average, rising production reflecting an increase in consumption attributed more to market value growth than for non-ferrous base metal markets.

Finally, other minor metals display an equally mixed record. For the majority of metals, market value growth stemmed from an increase in real price, which overcompensated falling production in the case of thallium. In the case of rhenium and germanium, growth resulted mainly from a rising production. Market value growth for gallium and beryllium was negative despite rising production due to falling real prices. Market value of tantalum fell due to falling prices and falling production.

2.4 Summary

The recent boom in commodity prices beginning in early 2000 is extraordinary both in duration and magnitude, even compared with earlier super cycles as illustrated in chapter 2.2. Particularly refractory metals, albeit smaller in volume and absolute market value than non-ferrous metal markets, experienced a remarkable growth in market value since the beginning of the boom, driven by an increase in real prices as well as growing consumption approximated by production.

Both the distinctiveness of the price boom and the rising economic relevance of refractory metals carry several implications. The extraordinary persistence and magnitude of the boom and the fact that in several metal markets prices remained at an elevated level compared to their historical average despite experiencing one of the worst economic crises in history lends

support to HUMPHREYS' argument that prices may stabilize at a higher level[56]. It also casts doubt on the view that marginal production costs will remain largely unchanged after the boom compared to historical levels. Rather, it is a reasonable hypothesis that selected metal markets experienced a supply side structural change, which essentially means marginal production costs may be irreversibly higher than before the boom.
With respect to refractory metals, they have emerged as a new class of raw materials during the boom. Formerly taken as available abundantly at low cost, an industrial consumer's spending reserved for a basket of refractory metals had increased by a factor of over seven by the end of the boom compared to pre-boom levels, an increase almost twice that of non-ferrous base metals during the same time period. This increase in spending can only be justified by a correspondingly high economic value these metals add to steel grades and to the end products and is a reflection of the growing importance of refractory metals to economic growth. Thus, the role of refractory metals with respect to their cost and revenue position has changed significantly.

Furthermore, the perception of resource scarcity has brought up the question of resource security from the realms of the past. The measures taken both by China as a major consumer and exporter of metals as well as the countermeasures of major importing regions illustrate how serious the threat to resource security is evaluated. The growing importance of refractory metals therefore also carries a new risk component to be considered by market participants and policy makers.

In this context, it is imperative to understand the underlying demand structure of refractory metals to explain the roots of the growing economic value these metals effectuate, the factors influencing the supply and availability of refractory metals and to trace these structural influences back to their impact on price.

[56] Humphreys (2009), p.104

3. Research background

In the previous chapter, the distinctiveness of the price boom lasting from early 2000 to mid 2008 as well as the rising economic importance of refractory metals as a sub-group of minor metals were emphasized.

In this chapter, existing literature is reviewed examining the development of metal markets. Chapter 3.1 is concerned with research on long-term metal prices and underlying factors identified to impact the long-term price level and volatility. In chapter 3.2, literature on metal demand is covered to assess the relevant structural influences and their impact on the price of a metal as well as to review methodologies to analyze metal demand. In chapter 3.3, research on metal supply is examined to gain an overview of relevant structural factors influencing the supply of metals and their corresponding impact on the metal price. In all chapters, the coverage of refractory and minor metal markets compared to non-ferrous base metal markets is assessed. Chapter 3.4 provides a summary in the form of research gaps deduced and devises research questions to be answered in this work.

3.1 Review of literature on long-term metal price development

The formation of prices for commoditized products such as metals is the result of demand and supply factors. However, short-run price elasticities of demand and supply are both low. Demand for metals is usually not deferred in the short-run when prices are high as measures to switch to alternative materials take long to implement once destocking has been carried out. Short-run price elasticity of supply is also low as short-run capacity expansions are constrained in mining and processing, i.e. smelting, refining, and treatment. Short-term price development of metals is therefore rarely a reliable indicator for the longer term.

Scientific research on metal prices relevant in the scope of this work thus focuses predominantly on analyzing prices over a longer period of time. Under such extended scope, price development may reflect long-term trends and discontinuities with a persistent impact on prices. Literature in this field may be clustered along its objective, which is either to analyze the cyclicality, the overall long-term trend or the volatility of metal prices and the approach, which is either based on statistical analysis or visual inspection combined with industry knowledge. Exhibit 10 provides a schematic overview:

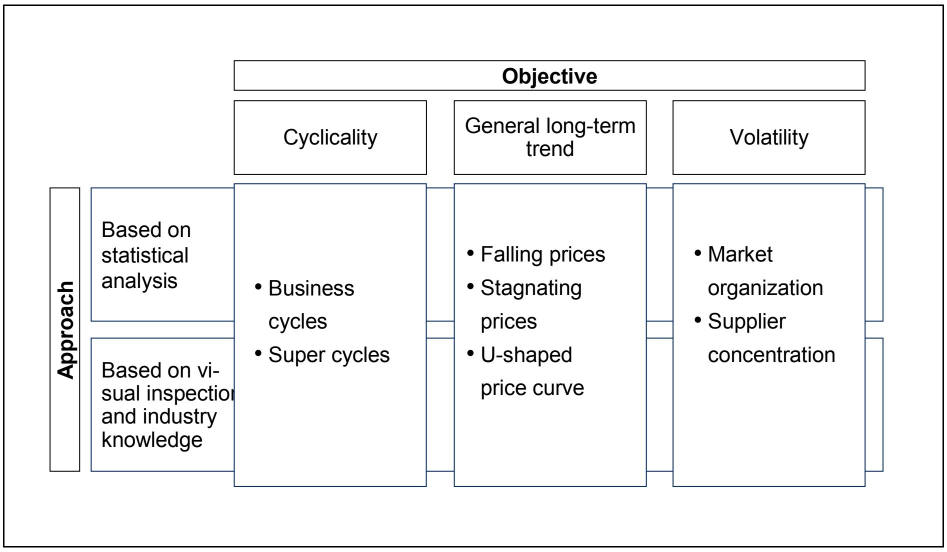

Exhibit 10 – Classification of research on price development

Source: Own illustration

Research concerned with the cyclicality of metal prices attempts to identify regularities in the movement of real prices, i.e. identifying reoccurring periods of real price booms and slumps as well as measuring amplitudes and lengths of periods of price contraction and expansion. Scholars generally distinguish between business cycles with a complete cycle length, i.e. price rise and slump, between 1 to 2 year and below 8 years[57] and super cycles with a complete cycle length between 20 and 70 years[58].

A major motivation for analyzing metal prices under the premise of identifying a long-term trend stems from the use of real prices as an indicator for growing metal scarcity. Given the nonrenewable character of metals, the depletion of metal assets has been predicted for a long time. The cost of depletion should consequently be reflected in the rising real prices of metals. However, scholars fail at large to detect long-term rising prices. Generally, studies maybe categorized according to the detected price trend, which is either falling, stagnating or developing along a u-shaped form.

Factors influencing the long-term volatility of metal prices are thought to originate in the market organization, i.e. the interface between supply and demand as well as in the degree of supplier concentration.

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[57] Roberts (2009), p.93 sets the minimum length for expansion and contraction periods at 6 months, i.e. 1 year for one complete cycle. Jerret/Cuddington (2008), p.190 range business cycles from 2 to 8 years

[58] Jerret/Cuddington (2008), p.188

In the following subchapters 3.1.1, 3.1.2, and 3.1.3 literature on the three objectives is reviewed with the intention to identify underlying market forces initiating persistent price discontinuities and to assess the consideration of refractory metals. In chapter 3.1.4 findings are summarized.

3.1.1 Metal price cyclicality

As discussed in chapter 2.2, the price boom in metal prices is widely classified as a new super cycle[59] rather than a mere business cycle. A review of literature focusing on the former is therefore justified to gain a better understanding of underlying market forces. Nonetheless, literature on business cyclicality may yield important insights regarding the underlying drivers of discontinuities in prices.

Representative studies concerned with business and super cycles are listed in Table 1 along with the metal sectors and the time period covered.

Sub-category	**Author**	**Findings**	**Metal sector (s)**	**Time period**
Business cycles	Roberts (2009)	• Cyclicality statistically insignificant for most metals due to great variability • Booms and slumps offset each other, therefore no evidence for long-term trend	Aluminum, copper, nickel, lead, tin, zinc, silver, platinum, mercury, ferrous scrap, iron ore	1947-2007
	Cashin/ McDermott/ Scott (2002)	General asymmetry in commodity price cycles: • Price slumps last longer than booms • Prices fall larger in slumps than during rebound, therefore	Aluminum, copper, nickel, lead, tin, zinc, gold, iron ore	1957-1999

[59] Jerret/Cuddington (2008); Cuddington/Jerret (2008)

Sub-category	**Author**	**Findings**	**Metal sector (s)**	**Time period**
		evidence for long-term falling price trend • Probability of slump end (boom) independent of time already spent in slump(boom)		
	Labys/ Kouassi/ Terraza (2000)	• Evidence for cyclicality • Differences within metal markets concerning number of cycles, length and amplitude	Aluminum, copper, gold, lead, nickel, silver, tungsten, tin, zinc	1960-1993
	Labys/ Lesourd/ Badillo (1998)	• Cyclicality statistically significant • Shorter term cyclicality than previously confirmed	Aluminum, copper, lead, nickel, tin, zinc, gold, silver, tungsten	1960-1995
	Davutyan/ Roberts (1994)	• Degree of cyclicality for duration can be established • Standard deviation too large to predict turning point	Lead, zinc, mercury, tin, copper	1850-1991 (sometimes shorter depending on metal)
Super cycles	Cuddington/ Jerret (2008)	• Strong evidence for super cycles in analyzed metals	Aluminum, copper, nickel, lead, tin, zinc	1850-2006 (depending on metal)
	Jerret/ Cuddington (2008)	• Strong evidence for super cycles in analyzed metals	Molybdenum, steel, pig iron	1912-2004

Sub-category	Author	Findings	Metal sector (s)	Time period
	Heap (2005)	• Recent boom period beginning of new super cycle driven by demand from China	Copper	1885-2004
	Nelson/ Kang (1981)	• Little evidence for super cycles in commodity prices	Not applicable	
	Radetzki (2006)	• 3 commodity booms since 2nd World War • All booms are demand driven	Metal index	1949-2006
	Radetzki/ Eggert/ Lagos/ Lima/ Tilton (2008)	• Recent boom caused by lag in establishment of new capacity	Not applicable	
	Humphreys/ (2009)	• Capacity lag alone inconclusive as driver for price boom	Not applicable	

Table 1 – Studies on cyclicality in metal series
Source: Own illustration

- **Business cycles**

Research on this topic argues that commodity prices reflect short-term economic development or business cycle activities.[60] Researchers are generally divided as to whether the price development of the past incorporates a degree of recurring periodicity and therefore if it is at all justified to speak of cyclicality. Most authors reject the hypothesis of a random walk on the grounds of statistical analysis, thus emphasize the relevance of their work. Yet, their data suggests a large degree of variability. DAVUTYAN/ ROBERTS point out that while they

60 Labys/Lesourd/Badillo (1998), p.147

have been able to establish a duration dependence of price cycles, the standard deviations are too large to develop "any ability to predict the turning points"[61]. ROBERTS notes that "there is such great variability in the duration of these phases that there are few cases of statistically significant differences"[62]. CASHIN et al. point out that there appears to be a general asymmetry in price cycles. Slumps last generally longer than booms and the probability of slump end (boom) is independent of time already spent in slump (boom). Also, prices fall larger in slumps than during rebound, therefore supporting the view of a long-term falling price trend. This latter point is rejected by ROBERTS who concludes that "price rises during expansions are by and large offset by falls during contractions thus there is little evidence for long-term trends in real metal prices"[62].

LABYS et al. fall back to perceived structural breaks in metal prices based on macroeconomic developments to meet required conditions of non-autocorrelation and homoscedasticity for their sample period. They then go on to identify business cycles in between these structural breaks. They divide the sample period from 1960 to 1993 into five "appropriate sub-periods, representing the major macroeconomic expansions and recessions since 1970, i.e. structural benchmarks"[63]. They refer to work of BADILLO et al. who, however, identified only one and not five structural breaks based on statistical analysis within a similar time period,[64] so the origin of the chosen sub-periods remains unclear. No attempt is being made to relate these alleged structural breaks to metal specific underlying industry drivers.

- **Super cycles**

Super cycles are defined as long-term cycles spanning 20 to 70 years according to CUDDINGTON/JERRET. Research on super cycles is motivated by the long gestation periods of mining projects. DAVIS/SAMI observe that "An analysis of 54 major base-and precious-metal deposits around the Pacific rim by Sillitoe (1995) reveals that the time from initial exploration spending to the discovery drill hole averaged 14 years for base metal deposits and 22 years for gold deposits. There is then an average of a further 13.5 years to first production for base metal deposits and seven years to first production for gold deposits. That is, where exploration is successful there is an average of 27.5 years from initial spending to cash flow generation for base metal deposits. The average at gold deposits is 29 years"[65].

61 Davutyan/ Roberts (1994), p.56

62 Roberts(2009), p.97

63 Labys/Lesourd/Badillo (1998), p.152

64 Badillo/Labys/Wu (1999), p.324

65 Davis/Sami(2006), p.?; Sillitoe (1995), p.119

Obviously, some mining projects will ramp up faster, since not all are greenfield projects. Also, exploratory drilling is rarely followed directly by setting up a production site. Rather, initial drilling results may be put on hold to secure financing or to replace depleting sites. Nonetheless, evidence for the existence of long-term cycles would be important for mining companies for investment decisions, for countries relying on mining revenues through direct ownership or taxes and royalties and not least for consumers of metals to assess their future cost position.

Research on super cycles in commodity prices goes back to so-called Kuznets or Kondratiev cycles, named after their authors. However, due to inappropriate statistical techniques, findings regarding the existence of such cycles have been met with some skepticism.[66] Consequently, analysis of longer term cycles with specific attention to metal prices is scarce and work on shorter business cycles prevailed. However, recent work by CUDDINGTON/JERRET and JERRET/CUDDINGTON, motivated by efforts of economists focusing on macroeconomic data, e.g.,COMIN/GERTLER[67], has addressed earlier critic of lack of statistical rigor. Using band pass filtering techniques the authors conclude that they have strong evidence for the presence of super cycles in the six non-ferrous base metal prices as well as in prices for steel, pig iron and molybdenum.

Having observed the existence of three previous super cycles based on statistical analysis, CUDDINGTON/JERRET and JERRET/CUDDINGTON emphasize the need for understanding the underlying drivers for this behavior and relate the cyclicality to structural changes on the demand and supply side: "Now that SCs have been measured and detected, explaining the factors driving these large price cycles becomes a high-priority task. Building a multi-sectoral model of the structural changes accompanying economic development, with explicit supply and demand roles for metals, would appear to be a productive approach to this modeling effort"[68].

RADETZKI, in his study of the anatomy of previous commodity price booms based on visual inspection, notes that "global growth of GDP and industrial production accelerated strongly in the periods just preceding or marking the beginning of the three commodity booms. This coincidence is so clear that I venture the assertion that all three commodity booms were importantly, though not exclusively, triggered by 'demand shocks'"[69]. He further concludes

[66] Nelson/ Kang (1981), p. 741f.

[67] Comin/Gertler (2006), p. 523f.

[68] Jerett/Cuddington (2008), p.195

[69] Radetzki (2006), p.63

that "In my view, changed supply responses are not needed to explain the past and current events"[70], thus exempting structural supply side changes from bearing any influence on long-term price development. He also does not expect a long-term effect on raw material price levels from the economic rise of China and India: "Will this scenario [economic successes of China and India] have a bearing on the frequency, strength and duration of future commodity booms and the long run raw material price levels? I think not"[71]. He asserts that increasing demand for raw material in these countries results in increasing exports of manufactures and will be offset by reduced imports of raw materials from importers of these manufactures. Interestingly, he does not address the demand increase driven by rising domestic demand in these countries but treats the demand for raw materials between developing countries and developed countries as a zero sum game. He furthermore reasons that "Commodity producers can ordinarily accommodate speedily expanding demand without inflating costs if the demand trend is anticipated"[72]. Accordingly, supply capacity can always be added at the same cost of existing capacity.

An analysis of HEAP draws a slightly different conclusion. He is in agreement with RADETZKI and JERRET/CUDDINGTON that the beginning of the new millennium marks the beginning of a new super cycle. While he concedes like RADETZKI that demand is the driver for the boom he differentiates that "Greatest metals demand exists in China's domestic market – not its export market"[73]. Furthermore, he explicitly names structural changes on the supply side as drivers of the price boom by stating that "production costs are likely to continue rising on a structural basis. The additional supply required to meet higher trend demand growth will be higher cost"[74]. However, he does not elaborate on factors that would drive a supply side structural change.

In a later work, RADETZKI et al. label the recent boom in commodity prices as distinguished compared to other booms due to its durability. They suspect that a lag in the installation of new capacity is the main cause, i.e. they concede that supply side factors are also responsible for the price upswing. They conclude however, that once capacity is available, the price boom will end.[75] This is questioned by HUMPRHEYS, who hypothesizes whether prices may plateau at a new elevated level. He also argues that "There may, nevertheless, be a supply-side

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[70] Ibid.

[71] Ibid.

[72] Radetzki (2006), p.63

[73] Heap (2005), p.2

[74] Heap (2005), p.17

[75] Radetzki/Eggert/Lagos/Lima/Tilton (2008), p.125

dimension to this argument about structural change that could possibly have longer lasting significance for mineral prices"[76]. He sees the dramatic growth in availability of low-cost labour as key driver for the reduction of manufacturing cost, but estimates the effect on capital intensive extraction to be much smaller. The recent price boom according to him is therefore to a certain extent driven by "the resurgence of manufacturing [that] has a galvanizing effect on the demand for raw materials"[77].

3.1.2 Long-term trends in metal prices

Given that academic literature in this field attempts to isolate a single trend over a long period of time, the scope of each study with respect to the time period concerned and the metal markets covered may influence results greatly. The time period chosen has an obvious influence on the results. The time around 1975 is an often declared "structural break" in many studies. The notion of falling metal prices in real terms is very much influenced by a perceived persistent decline in metal prices since the end of the 1970s. Furthermore, for lack of accounting for spurious correlation, some analyses based on statistical methodology rather than solid industry knowledge may reach different conclusions than others.[78] Finally, the outcome of the analysis depends very much on the deflator used to discount nominal prices.[79]

Numerous empirical studies on the long-term trend of commodity prices have been conducted and it is beyond the scope of this work to review them all. Representative studies, which for the most part focus on metal prices are listed in Table 2:

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76 Humpreys (2009), p. 103

77 Humpreys (2009), p. 104

78 Ahrens/Sharma (1997), p.59

79 Svedberg/Tilton (2006), p.501f.

Author	Findings	Metal sector (s)	Time period
Potter/ Christy (1962)	• Falling trend in mineral commodity index comprising 14 metals, 4 energy commodities, 14 nonmetal prices • Drivers for trend not specified	• Index of iron ore, pig iron, steel, ferro-alloys, ferro-manganese, nickel, tungsten, copper, lead, zinc, bauxite, aluminum, tin, magne-sium	1870-1957
Smith (1979)	• No continuous trend • Price series analysis insufficient for price predictions	• See Potter/Christy (1962)	1900-1973
Slade (1982)	• Prices follow u-shaped price curve, first falling, then rising	• Copper, aluminum, lead, nickel, tin, zinc, silver, iron ore	1870-1978
Berck/ Roberts (1996)	• Evidence that real prices of metals are trendless	• Copper, aluminum, zinc, silver, iron ore	1870-1991
Ahrens/ Sharma (1997)	• No particular trend in metal prices can be generalized	• Copper, aluminum, lead, nickel, tin, zinc, silver, iron ore	1870-1990

Author	Findings	Metal sector (s)	Time period
Krautkraemer (1998)	• Falling trend in metal real prices	• Copper, aluminum, lead, nickel, tin, zinc, silver	1967-1995
Cashin/ McDermott/ Scott (2002)	• Declining price trend • No evidence for break in this trend	• Industrial commo-dity index	1982-1999
Svedberg/ Tilton (2006)	• Trend in prices depends on adjustment of inflation deflator	• Copper	1870-2000

Table 2 – Studies on long-term trends in metal price series

Source: Own illustration

As summarized in Exhibit 10, Table 2 indicates the range of conclusions reached by authors analyzing the long-term development of metal prices. Rather than reviewing all studies, a summary is provided to distill relevant opinions and patterns.

Several theoretical models have predicted a rise in metal prices due to growing scarcity for centuries.[80] Later studies, initiated by a first systematical approach conducted by POTTER/CHRISTY found that a mineral price index comprising fourteen metals, four energy commodities, and fourteen nonmetals, fell by 40% in real terms during the observed period.[81] POTTER/CHRISTY's systematic analysis triggered a range of scientific studies, which identify two general opposing market forces influencing metal prices:

- Increase of extraction costs due to declining ore quality
- Declining cost of production due to technical innovation

The perceived interaction of these two forces is a strong determinant of the predicted price trend. In this context, a study by SLADE received considerable attention. Based on an analysis of the six non-ferrous base metals and silver and a model that uses as variables exogenous technical change and endogenous change in the grade of ores mined, she

80 For a review of the earlier evolution of such concerns, compare Tilton(2003), p. 7ff.

81 Potter/Christy (1962)

concludes that there is "a U-shaped time path for relative prices"[82]. This trend is driven by "the historic counterbalancing influences of improvements in technology and deterioration in ore quality in determining production cost"[83]. For an industry example, she points to the copper industry in the US, where copper ore graded declined from 1900 to 1980 from 5% to 0.7%. Despite such fall in ore quality, real copper prices fell until 1940 due to innovations in mining technology and equipment. As since then prices have been on the rise, she reasons that technological innovation is saturated and that declining ore grade continues to dominate production costs.

Several authors object her findings. For one, it is pointed out that despite warnings of growing scarcity and rising cost of depletion, prices continued to fall after the period examined by SLADE. KRAUTKRAEMER observes that "nonrenewable resource prices did not continue to trend upward after the 1970s"[84], thus rejecting SLADE's findings. He concludes that "there isn't a stable linear trend to most resource price time series"[85]. As a major reason for the lack of an upward trend in prices he points to technological innovation overcompensating the cost increases of declining ore grade. The same argument is repeated by GOMEZ et al. who conclude that the decline in the real price of copper is "a decline largely driven by the highly successful efforts of primary copper producers to reduce their production costs over this period"[86]. TILTON/LAGOS go even further and suggest that the ability of technical innovation to reduce extraction cost may go on indefinitely: "the challenge for innovation and new technology in keeping the cost-increasing effects of depletion at bay may be no greater in the future than it has been in the past"[87].

Other authors generally oppose the idea of identifying any trend on the basis of mere price analysis. Refining POTTER/CHRISTY's analysis, SMITH concludes that their and others findings that metal prices are following a certain trend is premature. He emphasizes that drawing conclusions on price series alone is unwise as a detailed knowledge of the underlying market structure and its changes is inevitable: "evaluations of resource scarcity without

82 Slade (1982), p.126

83 Slade (1986), p.126

84 Krautkraemer (1998), p.2079

85 Ibid.

86 Gómez/Guzmán/Tilton (2007), p.189

87 Tilton/Lagos (2007), p.22

detailed analysis of the character of the markets for the specific commodities within each aggregate, as well as the institutional changes during the period, do not seem possible"[88].

3.1.3 Price volatility

Academic literature on commodity price volatility focuses predominantly on two main topics influencing the level of volatility:

- the impact of market organization
  - exchange prices versus administered producer prices
  - trading of futures and forwards
- the impact of supplier concentration

An overview of studies focusing on metal price volatility is presented in Table 3:

Sub-category	Author	Findings	Metal sector (s)	Time period
Market organization	Slade (1991)	• Volatility increased due to structural change in market organization	Aluminum, copper, lead, nickel, silver, zinc	1970-1986
	Brunetti/ Gilbert (1995)	• Volatility is stationary • Speculation has only short-term influence • Medium-term influence on volatility stems from physical factors	Aluminum, copper, lead, nickel, tin, zinc	1972-1995
	Figuerola-Ferretti/ Gilbert (2001)	• No evidence for increase in volatility • Change on market organization has no	Aluminum, copper, lead, nickel, silver, zinc	1970-1997

[88] Smith (1979), p.426

Sub-category	Author	Findings	Metal sector (s)	Time period
		impact on volatility		
	McMillan/ Speight (2001)	• Decomposition of volatility in long and short-term common factors • Long-term factors found to be influenced by other metal prices	Aluminum, copper, lead, nickel, tin, zinc	1972-2000
	Slade (2006)	• Volatility and volume forward trading positively correlated • No direct influence, linked by common factor	Aluminum, copper, lead, nickel, tin, zinc	1990-1999
	Cox (1976)	• Forward trading increases market efficiency	Not applicable	
	Simpson/ Ireland (1985)	• Future trading first decreasing, then increasing effect on volatility	Not applicable	
Supplier concen-tration	Carlton (1986)	• Higher level of industry concentration correlates with lower volatility	Steel, index of non-ferrous metals	1957-1966
	Slade/ Thille, (2006)	• Higher level of industry concentration correlates with lower volatility	Aluminum, copper, lead, nickel, tin, zinc	1990-1999

Table 3 – Studies on volatility in metal price series

Source: Own illustration

- **Market organization**

In a much recognized study on the impact of market organization, SLADE identifies five distinct areas from which price volatility originates:[89]

- Horizontal market structure, i.e. the concentration of the supply side industry[90]
- Marketing method, including the impact of market organization, more specifically price setting mechanisms in metal markets, namely so-called producer price setting, where prices are set by an oligopoly of major producers and exchange-price setting. This in turn influences the motivation of buyers, i.e. if buyers are solely consumers or consumers, hedgers, and speculators
- Demand factors, comprising the stability of output of the consuming sector and the ease of substitution
- Supply factors, including the influence of cost stability, by-production, recycling on price stability
- Time-period factors, i.e. exchange rate and rate of inflation

Of these five factors she determines two, horizontal market structure and marketing method to be significant, i.e. measurable "with statistical accuracy".[91] Of these two, her analysis of the time period from 1970 to 1986 reveals that the structural change in the marketing method appears most influential: "The increase in metal-price instability that has occurred in the last decade is entirely explained by changes in underlying market-structure and organization variables considered here. Foremost among these is increased reliance on commodity exchanges, which accounts for a significant fraction of the systematic variation across markets."[92]

Subsequent studies question both the finding that volatility has increased and the conclusion that a structural change in market organization is to blame. In their research on the price volatility of aluminum, copper, lead, nickel, tin and zinc between 1972 and 1995, using daily prices, BRUNETTI/GILBERT find no evidence that volatility has increased over time. On the contrary they observe that "except in the case of tin, volatility levels were beneath their

[89] Slade (1991), p.1311ff.

[90] Slade does not specifically name the supply side when speaking of horizontal concentration. From the data she uses for her analysis, however, it becomes clear which industry she means.

[91] Slade (1991), p.1311. It is unclear on what basis she excludes the other three.

[92] Slade (1991), p.1337

historic average levels over 1993-95, a period of increased speculative interest in the metals markets"[93]. However, they find that volatility is itself volatile and distinguish three explanations for changes in metal market volatility:[94]

- Information considerations: price adjustments on the basis of new information
- Hedging or speculative pressure
- Physical availability

They argue that while informational considerations and speculative pressure do have an impact, theirs appears to be only short-term. They conclude that "much of the medium-term variability in the volatility of non-ferrous metals prices on the LME may be explained by physical (or fundamental) factors"[95]. Without elaborating what these fundamentals are specifically, they observe that a tight supply market with low stocks and little leeway to respond to demand or supply shocks is more volatile than a market with lower demand and large stocks.

Building on the findings of BRUNETTI/GILBERT, MCMILLAN/SPEIGHT decompose the volatility of six metals in common short- and long-term factors in an attempt to further quantify their impact. Yet they link the price volatility of metals to one another rather than attempting to develop a deeper understanding of the drivers for this proposed connection or generally of the impact of underlying industry factors on volatility. [96]

FIGUEROLA-FERRETTI/GILBERT extend the time period used in SLADE's analysis from 1970-1997. They divide this period into four sub-periods based on SLADE's example and visual inspection of data. Using similar statistical methods and monthly data they concur with SLADE that volatility till 1986 increased, but point out that silver was a dominant driver for this and that once silver is excluded, evidence for an increased volatility is much weaker. Extending the time period to 1997, they refrain from observing a "general tendency for the variability of exchange prices to increase over time"[97], thus rejecting SLADE's notion that a structural change in the market organization of metal markets had any influence on price volatility.

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[93] Brunetti/ Gilbert (1995) , p.237

[94] Derived from Brunetti/ Gilbert (1995), p.244

[95] Brunetti/ Gilbert (1995), p.245

[96] McMillan/Speight(2001), p.206

[97] Figuerola-Ferretti/Gilbert (2001), p.175f.

Another topic that has received considerable attention when comparing administered prices with exchange prices is the influence of forward trading on price volatility. Forward trading is made possible through the introduction of exchange trading of commodities. Scientific opinion on whether this form of trading increases of decreases price volatility is divided. An influential work by COX summarizes the empirical findings of his time and concludes that "a significant price effect of future trading reflects an increase in market information"[98], and more specifically that the comparison of seven non-metal commodities across a period including times of future trading and no future trading conceded a lesser volatility when future trading was allowed.

SIMPSON/IRELAND investigate the impact of financial futures on the cash market for treasure bills. Summarizing the scientific work of their time, they can find little evidence "on destabilizing speculation in financial futures markets "[99]. Based on their own analysis they conclude that there was indeed a volatility reducing effect when future trading was introduced but this effect vanished when trading volume increased.[100]

SLADE/THILLE conclude that while predictions of destabilizing speculation models is mixed, a positive correlation between the two variables price volatility and forward trading volume exist. However, testing for a direct connection between the two, they conceded that "the link between the two is not direct and that both variables are influenced by a common factor such as the arrival of new information"[101], thus refining earlier research, which observed a directly destabilizing effect. Their work is also a notably exception insofar that price data are analyzed together with underlying industry data, namely supplier concentration. This is unique as the focus on price data alone is the prevalent method of most price analyses.

- **Supplier concentration**

The impact of the level of concentration of the supplier side on price level and volatility has been investigated and debated for some time. Researchers analyzing the impact of industry concentration on price volatility are unusually unanimous in their findings that prices appear to be more stable in oligopolies. Two representative works on this topic are therefore only briefly presented.

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98 Cox (1976), p.1232f.

99 Simpson/Ireland (1985), p.372

100 Simpson/Ireland (1985), p.378

101 Slade/Thille (2006), p.251

Analyzing the price rigidity of steel and a price index of non-ferrous metals as well as other commodities and some manufactures, CARLTON concludes that "The level of industry concentration is strongly correlated with rigid prices. The more concentrated the industry, the longer is the average spell of price rigidity."[102] SLADE/THILLE observe the prices of the six non-ferrous base metals between 1990 and 1999 and concur with earlier observations that " commodities that are produced in more concentrated markets tend to have more stable prices."[103]

Another aspect of supplier concentration that is often analyzed together with its impact on volatility is the influence on price level. Several authors conclude that a higher supplier concentration leads to higher price levels. SLADE/THILLE suggest that "strong evidence that a more concentrated industry is associated with higher prices, as the conventional wisdom predicts"[104]. MAXWELL predicts a change in the price level of nickel due to a decreasing supplier concentration.[105]

3.1.4 Summary and evaluation

One can summarize that scientific studies of long-term price trends and price cyclicality based on statistical analysis generally assume an "agnostic view"[106] of the subject. The majority of studies are concerned with finding evidence for the existence of a phenomenon in price development, i.e. the "what" but fall short of the "why", i.e. the change in underlying market forces. In the majority of cases, scholars are concerned with analyzing price data and make little effort to relate findings to underlying market forces. The statistical rigour of many studies to identify and define price cyclicality or a long-term trend is thus unmatched by comprehensive empirical research on the causes of such phenomenon. In studies based on visual inspection attempts are made to relate price trends and discontinuities back to underlying market drivers. However, a reference to the stylized fact of technical innovation overcompensating the cost of depletion prevails. A notable exception is RADETKI's study on the anatomy of commodity super cycles. However, his conclusions are based on the analysis of a metals and mineral and other indices, thus remaining on an aggregated level. Studies on price volatility yield more tangible explanations as to which underlying industry factors influence volatility. Albeit divided in opinion, evidence suggests that a changing

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[102] Carlton (1986), p.638

[103] Slade/Thille (2006), p.249

[104] Slade/Thille (2006), p.246

[105] Maxwell (1999), p.14

[106] Cuddington/Jerret (2008), p.2

market structure towards exchange trading as well as supplier concentration has a measurable impact on metal price volatility.

A further insight from all reviewed studies on metal price development is that refractory or other minor metal prices are rarely in the scope of mineral economists. The exceptions reviewed in this work are listed in Table 4:

Author	**Refractory metals covered**	**Other minor metals**	**Data/ analysis constraint**
Potter/ Christy (1962)	Manganese, magnesium, ferro-alloys		Part of a metal index
Labys/ Kouassi/ Terraza (2000)	Tungsten		
Jerret/ Cuddington (2008)	Molybdenum		
Labys/ Lesourd/ Badillo (1998)	Tungsten		

Table 4 - Coverage of refractory and other minor metals in literature on metal price series

Source: Own illustration

Of thirty studies reviewed on metal price development, only four contain price series of refractory metals. POTTER/CHRISTY include manganese and magnesium as well as ferro-alloys in their work but only as part of an index with non-ferrous base metals. LABYS et al. include a price series of tungsten. Neither authors specify their choice. A notable exception are JERRET/CUDDINGTON, who justify their choice of a price series of molybdenum by assessing that the metal is "critical in the early phases of industrial development and urbanization"[107].

107 Jerret/Cuddington (2008), p.188

3.2 Review of literature on metal demand

The purpose of the following chapters is to review economic literature on metal demand with the aim to identify structural factors that are thought to predominantly influence metal prices as well as to gain an overview of methodologies to analyze metal demand. While the importance of these structural factors rooted in demand for metal price development is being acknowledged in studies on metal price development, a proper verification and substantiation in metal price research is largely absent.[108] Also, the metal markets covered are evaluated to assess whether the omission of refractory or other minor metals in literature on metal prices prevails.

Myriads of factors may potentially influence metal demand and numerous studies are devoted to understanding underlying structural factors and deduce demand models accordingly. Which factors are considered depends often on the analytical approach chosen. RADETZKI/TILTON identify four methodologies in academic literature[109] to analyze metal demand:

- Intensity of use technique
- Demand function estimation
- Production function estimation
- Input-output analysis

Of all methodologies, the intensity of use (IU) technique appears to be the most prominent. A series of theories emerged from it, attempting to find recurring, metal independent patterns of the development of metal used by an economy per unit of national income. The IU technique and theories derived from it will be reviewed in chapter 3.2.1. Another albeit less commonly applied methodology is the demand function estimation, which will be reviewed chapter 3.2.2. The production function estimation, which is employed less frequently is covered in brief in chapter 3.2.3. The input-output analysis is rarely used anymore and is therefore not explicitly reviewed in this work.

3.2.1 Intensity of use concept

The intensity of use concept constitutes that an economy's metal demand depends on the economy's macroeconomic development usually measured by GDP as well as by the

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[108] Compare chapter 3.1

[109] Radetzki/Tilton (1990), p.25ff.

economy's mix of product output and the individual metal concentration in each product.[110] Specifically, demand D_t of a metal may be expressed as:

$$D_t = \sum_{i=1}^{n_t} a_{it} P_{it} \tag{1}$$

where P_i denotes the economy's output of the *i*th final good in physical units, a_i the amount of the metal used for the *i*th good, and n_t the number of goods produced in the economy in the period of time *t*. Dividing the total output of the *i*th good P_{it} by the economy's income Y_t during *t* yields

$$b_{it} = \frac{P_{it}}{Y_t} \tag{2}$$

Substituting for P_{it} in (1) yields

$$D_t = Y_t \sum_{i=1}^{n_t} a_{it} b_{it} \tag{3}$$

and

$$IU_t = \frac{D_t}{Y_t} = \sum_{i=1}^{n_t} a_{it} b_{it} \tag{4}$$

From equation (4) it becomes clear that the intensity of use (IU) in time period t is a function of the material composition of product (MCP) a_{it} and the production composition of income (PCI) b_{it}. The former expresses the mix of materials used to produce individual goods while the latter expresses, which goods are produced in the economy.

The technique of applying the IU concept to a given metal consumption comprises a set of consecutive steps to analyze an economy's metal demand. Exhibit 11 provides an overview:

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110 Tilton (1988)

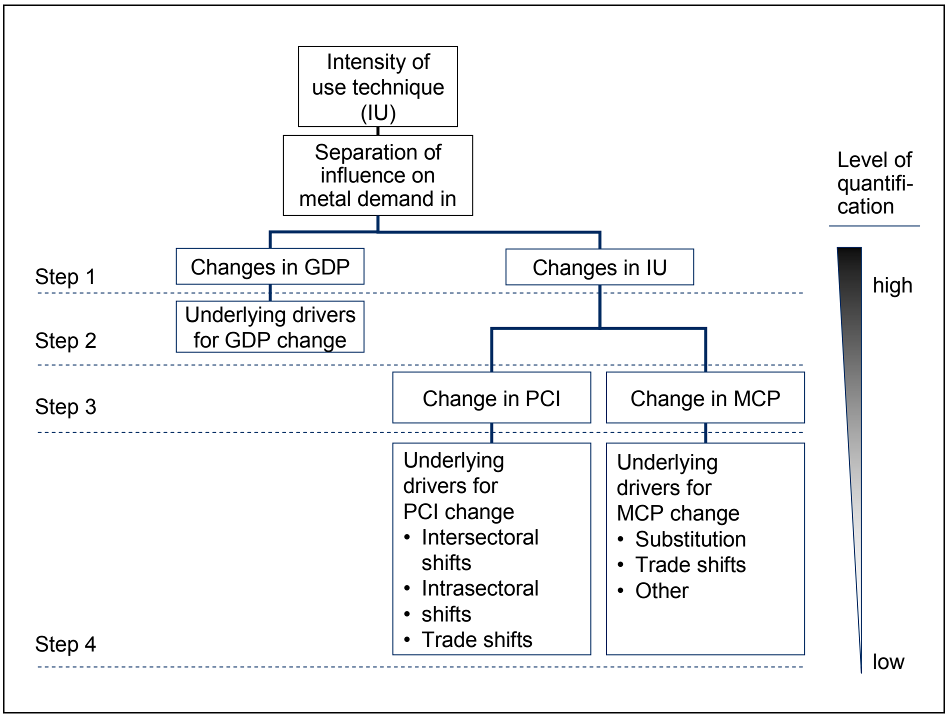

Exhibit 11 – Steps in intensity of use technique

Source: Own illustration, following Radetzki/Tilton (1990)

The first step separates to the extent possible changes in GDP from changes in IU. In a second step, if relevant, underlying causes for changes in GDP are assessed. As this step is a field of its own and often beyond the scope of studies analyzing metal demand, mineral economists tend to draw on research from this field or take GDP change as given. In a third step, it is attempted to split changes in IU into the two general drivers: product composition of income (PCI) and material composition of product (MCP). Naturally, changes in PCI and MCP are ultimately driven by changes in underlying drivers, which are examined in a final step. For changes in PCI, intersectoral shifts, e.g., a declining industry sector versus a rising service sector or intrasectoral shifts, e.g., the rise of information technology and the subsequent shift towards different materials can be reasons for change. Underlying drivers for changes in MCP are thought to be driven, e.g., by substitution of new materials for older ones. An often quoted example is the replacement of copper by fiber optics in telecommunications[111]. As indicated on the right hand side in Exhibit 11, the level of quantification is decreasing with every step. While the separation of changes in metal demand between change in GDP and change in IU is relatively simple, the latter steps often have to be based on qualitative assessment and solid understanding of the industry and its interrelations. Nonetheless, the top

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[111] Key/Schlabach (1986), p.433f.

down procedure and the in-depth analysis of the IU technique is a reliable approach to identify underlying relevant industry drivers.

On the basis of the IU technique, several economic theories have been developed. The most influential is the concept of dematerialization, also named intensity of use hypothesis. The concept and academic literature concerned with it will be reviewed in chapter 3.2.1.2.

The development of the transmaterialization and the rematerialization theory was sparked by several short-comings of the dematerialization theory. Both theories offer an alternative approach to dematerialization and are reviewed in chapter 3.2.1.2.

In the following subchapters, academic literature on both the intensity of use technique as well as the economic theories that are based on it are reviewed with the intention to identify empirically relevant underlying drivers for metal consumption.

3.2.1.1 Studies applying intensity of use technique

In this chapter, studies applying the intensity of use technique to metals and economies are reviewed in the attempt to identify underlying structural factors with a measurable influence on price. Also, the coverage of refractory or other minor metal markets is assessed. Table 5 contains and overview of relevant studies and their findings:

Subcategory	**Author**	**Findings**	**Metal sector (s)**	**Time period**
Intensity of use technique	Tilton (1985)	• Major structural change in intensity of use	Aluminum, nickel, copper	1950-1982
	Roberts (1988)	• Change in GDP and PCI are main drivers for structural break in metal consumption	Aluminum, copper, nickel, lead, zinc, steel, manganese, tin	1948-1984

Subcategory	Author	Findings	Metal sector (s)	Time period
	Radetzki/ Tilton (1990)	• Major structural change in intensity of use after 1973 • Economic performance alone not cause, no single factor dominant	Aluminum, copper, nickel, lead, zinc, steel	1960-1986
	Labson/ Crompton (1993)	• No evidence for relationship between economic growth and metal consumption	Copper, lead, zinc, steel, tin	1946-1989 (deviates for some metals)
	Labson (1994)	• Evidence for lock-step development of metal consumption and economic growth for selected metals	Aluminum, copper, lead, zinc, steel, tin	Updated data set, based on Tilton (1990)
	Tilton (1983)	• Different occurrences of substitution • Strongest impact from technological change	Tin	1960-1980

Subcategory	Author	Findings	Metal sector (s)	Time period
	Key/ Schlabach (1986)	• Technological change split in evolutionary and revolutionary • Strongest impact from revolutionary change	Copper, gold, cobalt, lead	1955-1985
	Ebensperger/ Maxwell/ Moscoso (2005)	• Industry sectors can be categorized according to life cycles	Lithium	1984-2003

Table 5 – Studies on metals applying the intensity of use technique

Source: Own illustration

One of the first systematic analysis of change in intensity of use of metals was triggered by a persistent decline in metal consumption per unit of GDP beginning the mid 1970s. TILTON is one of the first to address this phenomenon. According to him, "This change […] involves a sharp break or discontinuity in the growth of world demand for metals"[112]. He analyzes that only a part of metal consumption decline can be attributed to decline in GDP and conjectures that changes in material composition of product (MCP) and product composition of income (PCI) may be responsible for much of the unexplained change. Continuing his research TILTON five years later investigates the decline in metal demand growth for the OECD countries, applying the framework as illustrated in Exhibit 11 to five non-ferrous metals and steel. He calculates that for most metals a change in intensity of use (IU) was the dominant driver of consumption decline and goes further to analyze how the change in IU can be split in change in MCP and PCI by reviewing case study literature on occurrences of substitution and resource-saving technology as well as inter- and intrasectoral trend patterns. A relevant conclusion in the context of this work is that he is not able to pinpoint a single dominant responsible factor explaining the differences in IU between OECD

112 Tilton (1985), p.131

countries nor the overall decline in consumption. His final remark illustrate the difficulty of singling out any major factors in the final step of the IU framework: "The slowdown and in many instances reversal of IU growth are the result of important changes in both the material composition of products and the product composition of income, which in turn reflect the combined effects of material substitution, resource-saving technology, an expanding service sector, and the rise of high-technology products within manufacturing"[113].

In the context of TILTON's work on OECD countries, RADETZKI focuses on the development of metal consumption in developing countries. He notes that IU does indeed rise in such countries and points out that "difference between the two groups [OECD and developing countries] is primarily due to their investment performance. […] Indeed, when IU is measured on the basis of GDI [real gross domestic investment], the rising trend in the developing countries remains only for aluminum and nickel, the 'new metals'. For the other metals the IU trend declined in striking parallel with developments in the industrialized economies"[114]. He furthermore points out that there is a large degree of variability in IU values between countries and concurs with TILTON that metal consumption by country does not follow any coherent pattern. Rather he relates differences in consumption to national policies and identifies these as the most important drivers for structural changes in metal consumption. He therefore concludes that any attempt to explain or forecast metal consumption based on general economic performance is flawed as it does not take into account these individual factors which greatly influence structural change.

Summarizing both findings on OECD countries and developing countries as well as centrally planned economies, TILTON concurs that economic growth and metal demand are linked but rejects the notion of a simple relationship. He suggests that the growth in GDP and growth in metal demand can be plotted as a linear relationship but axis intercept and the incline depend on the metal and the trend in intensity of use.[115]

Focusing on eight metals, ROBERTS investigates a similar time period as TILTON and RADETZKI. He attempts to calculate the rates for MCP and PCI on a global scale using metal dependent indices and then analyzes the impact of the two and GDP on the declining metal intensity of use. He shows that a drop in GDP and a declining product composition of income is to blame for a drop in IU, while the development of the MCP rate, albeit falling, is not accelerating its decline after 1973. He concludes that an increase in resource-saving

[113] Tilton (1990), p.73f.

[114] Radetzki (1990), p.110ff.

[115] Tilton (1990), p.262f.

technology or sudden material substitution is therefore not driving the decline in IU and speculates that the falling economic performance could be the reason for a change in consumer preference measured through PCI: "Lower per capita income has influenced consumers to shift away from purchases of heavy manufactured (durable) goods and investments towards more immediately necessary non-durables and other less metal-intensive products"[116]. However, analyzing a continuous decline in MCP over the time period of 1960 to 1985, he conjectures that while a decline in PCI and in income may be causing short-term changes in metal intensity of use, MCP appears to be the long-term factor for gradual structural change: "PCI explains the short-term (cyclical) variations. However, over the long term the overall trend in intensity of use, and therefore metal consumption, is controlled by factors which are most dependent on technology (measured by MCP)"[117].

LABSON's research questions that MCP related factors such as innovation and technological change cause structural changes. From a classical statistical perspective he analyzes metal intensity of use in selected countries and the OECD over a similar time period as ROBERTS, TILTON and RADETZKI. He concludes that if one accounts for a structural break in 1973, selected metals on OECD level exhibit a stationary process, which means that metal intensity of use follows indeed economic activity. He concludes that "for the most part, innovations are not of such a deep nature as to impart a permanent influence of intensity of use over reasonably interesting time horizons." According to his interpretation, "technological shocks are not as pervasive as one might have thought and that only the relatively large, but sporadic events have a measurably lasting influence on metal demand"[118]. However, he concedes that general conclusion based on his analysis should be considered with care as his findings are rather mixed, with the outcome varying by both metal and country.

The controversy of interpreting statistical findings on metal intensity of use analysis is illustrated by the fact that research published two years earlier by the same author, LABSON, rejects a stationary relationship between metal intensity of use and economic growth and suggests technological change, expressed by MCP, as an important driver for structural change. LABSON/CROMPTON analyze the same data as LABSON (1995) except that they exclude aluminum. They concede that "An important implication is that other random factors,

116 Roberts (1988), p.242

117 Roberts (1988), p.244f.

118 Labson (1995), p.41f.

such as technological change perhaps, have a permanent effect on the relationship between economic activity and metals consumption"[119].

In his in-depth review of the development of MCP in the case of tin, TILTON focuses on substitution occurring in three sectors of the tin industry: beverage containers, solder, and tin chemicals. Table 6 illustrates the different types of substitution he identifies[120]:

Substitution related to material composition of product	Substitution related to product composition of income
Material-for-material substitution	Interproduct or functional substitution
Technological change in manufacturing	
Quality change of product	

Table 6 – Causes for material substitution

Source: Own illustration, based on Tilton (1983)

Material-for-material substitution comprises the substitution where one material is substituted for another. An often quoted example is the substitution of the aluminum can for the glass bottle.

Technological change in manufacturing may result from a change in input factors that impact the material intensity of production, e.g. the automated production of electronic products using of printed circuit boards is more tin intensive than hand soldering but the automated process is less labor intensive and therefore less costly. Interproduct or functional substitution describes the change in the mix of goods needed by a society. One example is the rise of cellular phones and the decline of landlines, which impacts the use of copper for telephone lines.

The change of quality of a product may influence the material composition or material intensity of a product. TILTON suggests the use of lightweight glass bottles as an example for the reduction of the amount of glass used per bottle. He identifies three prevailing forces for material substitution:

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119 Labson/Crompton (1993), p.149

120 The following paragraph follows Tilton (1983), p.1ff. – Tilton defines in fact five different types of substitution. The occurence "technological change in manufacturing" in Table 6 summarizes both his definition for "other-factors for material" substitution and "technological" substitution.

- **Relative material price**
  In contrast to the wide spread belief that the price of a material relative to a substitute is the principal motivation for substitution, TILTON finds that evidence on this topic is mixed. He concludes that the impact of the relative price depends on the share of tin's price of total production cost, which lessens with the proceeding stage of production: "the price of tin has its greatest impact on material substitution at relatively early stages of production […].This is in contrast with the material substitution at later stages of production, which has significantly increased the use of tin. […] At […] these stages, the price of tin has had a small impact on final costs, and has easily been offset by other considerations"[121].
  When price is affecting material substitution, the author distinguishes three different responses:[122]

  - Immediate change between substitutes according to material prices
  - Lagged substitution due to high lock-in costs with the material to be substituted. Substitution occurs only when it is assumed that relative price gap between old material and substitute is not temporary. Switching back requires price of the replaced material to fall considerably and sustainably below old threshold price.
  - Lagged substitution because new technology is required to replace the old by new material. High capital cost make a switch back unlikely even in the event of falling prices of the original material relative to the substitute

  TILTON describes the last type of response as the one with the strongest impact on tin consumption. He therefore concludes that "change in material prices typically have little effect on the mix of materials in the short run because producers are constrained by existing technologies. Over the long run, they have more impact"[123].

- **Technological change**
  The importance of technological change as a response to increasing relative material prices directly corresponds with the case of lagged substitution due to the introduction of new technology. Embarking on technological change to substitute for a material appears to be the most sustainable and irreversible form of substitution according to TILTON. He also emphasizes the unpredictable nature of this form of substitution: "its impact has often

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121 Tilton (1983), p.5

122 Ibid.

123 Tilton (1983), p.7

been abrupt and uneven, at times stimulating and at other ties curtailing tin use. This random and discontinuous character of technical change makes it difficult to foresee its effects"[124].

- **Government regulation**
  "While less important than technological change, the influence of this factor appears to be growing over time"[125]. TILTON identifies the growing influence of numerous government agencies on material use, either directly through regulation of material use due to health concerns, or indirectly through promoting technologies such as more fuel efficient automobiles as a driver for substitution whose importance is rising, albeit less prevalent than the two others mentioned above.

Though not mentioned explicitly by TILTON, the differentiation between the prevailing forces of substitution is difficult as they may be interconnected. E.g., technical change may be triggered by government regulation.
Based on his findings, TILTON concludes that several assumptions in demand function estimation[126] are implausible. In particular, he questions the concept of reversibility and the stability of the demand-price function, as commonly assumed in economic theory: "if the principal effect of a change in price on material demand occurs indirectly via induced technological change, as the studies here suggest, this approach reduces the demand curve to a sterile academic concept with little practical use"[127]. Furthermore, he conjectures that substitution can alleviate supply shortages based on structural changes in supply such as depletion of low cost, high-grade ores but appears insufficient to make a significant contribution to short to medium-term cyclical changes in supply causing corresponding price cycles, because of the lagged response of substitution measures, notably technological change.
With respect to supplier power in concentrated markets he concludes that "Material substitution, however, can severely limit market power even in highly concentrated industries. Collusive efforts by established producers to raise prices substantially are likely to stimulate new technological activity, and eventually end in failure, with markets irretrievably lost"[128]. In the context of forecasting consumption he emphasizes the need to consider explicitly the complexities of substitution.

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124 Tilton (1983), p.6

125 Ibid.

126 Compare chapter 3.2.2

127 Tilton (1983), p.8

128 Tilton (1983), p.9

The importance of technological change as an impactful occurrence of substitution is reflected by research of KEY/SCHLABACH who analyze the intensity of use of the US telecommunications industry for copper, lead, gold, and cobalt. They distinguish two types of technological change and identify respective drivers for each type[129]:

- Evolutionary change
    - Miniaturization (all metals)
    - Material effectivity (gold)
    - Supply security (cobalt)
- Revolutionary change
    - Copper for optical fibers
    - Lead for polyethylene

They authors thus refine TILTON's analysis of technological change and concur that revolutionary technological change is "associated with major, rapid replacement of an existing technology"[130], i.e. they indicate the profound impact of such change on the structure of demand and its lack of predictability.

3.2.1.2 Dematerialization

As mentioned in the introduction of chapter 3.2, the most influential economic theory that emerged from the intensity of use (IU) technique is the dematerialization hypothesis. It postulates that the IU of an economy is a function of its economic development, which is expressed as GDP per capita, and that intensity of use of a metal is dependent on the stage of economic development of a nation. At an early stage of economic growth, per capita GDP is low as are material requirements due to the dominance of an agricultural sector largely relying on manual labor. As the economy shifts towards industrialization, material-intensive and particularly metal intensive activities such as manufacturing, construction, and establishment of an industrial infrastructure expand. This leads to a rising intensity of metal use. At some stage, however, these metal intensive activities reach a level of saturation, as infrastructure is installed and demand for houses, roads, factories and technical equipment is satisfied and demand shifts towards services, which are less metal intensive. Thus, according to the

[129] Key/Schlabach (1986), p.442ff.

[130] Key/Schlabach (1986), p.450

hypothesis, intensity of use peaks and starts to decline, while the economy continues to grow in the service sector. In academic literature this last step is often termed dematerialization, implying that economic growth in developed countries is decoupled from rising metal consumption.[131] The theory also implies a gradual structural change of the product composition of income (PCI), which according to the theory dominates other trends such as substitution and technical change.

The rationale underlying this concept gained popularity not least because of its simplicity. It also offers an explanation why the threats of scarcity and depletion of non-renewable materials have not yet materialized. The theory is widely dismissed today, yet initiated a series of studies on metal demand development and a host of other theories. Numerous studies analyze the veracity of this theory. A representative overview is given in Table 7:

Author	**Findings**	**Metal sector (s)**	**Time period**
Malenbaum (1978)	• Consistent dematerialization of developed industries due to structural change towards less intensive services	Steel, iron ore, nickel, manganese, chromium, cobalt, tungsten, copper, aluminum, platinum, zinc, tin	1951-1975
Fischman (1980)	• Declining intensity of use in developed countries	Aluminum, chromium, cobalt, copper, manganese, lead, zinc	1950-1977

131 Radetzki/Tilton (1990), p.27f.

Author	Findings	Metal sector (s)	Time period
Auty (1985)	• Existing evidence for dematerialization flawed • Indication of cyclical substitution	Tin, nickel, zinc, copper, lead, aluminum	1970-1982
Wernick/ Herman Govind/ Ausubel (1997)	• Mixed evidence of dematerialization along the value chain	Aluminum, copper, zinc, lead, steel	1900-1990
Cleveland/ Ruth (1999)	• Existing research on dematerialization exhibits significant short-comings • No compelling evidence for dematerialization	-	Review of studies covering time period between 1890-1994
Fortis (1994)	• IU development follows specific macroeconomic phases • Microeconomic developments cannot be ignored	Aluminum, lead, copper, pig iron, steel	1860-1990 (USA) 1946-1990 (Italy)
Labys (2004)	• Indication of cyclical substitution as opposed to dematerialization	-	-
Bringezu/ Schütz/ Steger/ Baudisch (2005)	• No evidence for consistent trend towards dematerialization • Declining	Aggregated index of metals and minerals	Not specified

Table 7 – Studies on dematerialization

Source: Own illustration

One of the most influential analyses, which sparked a lively discussion on dematerialization stems from MALENBAUM. He analyzes the IU for twelve metals between 1951 to 1975 for the world economy by dividing them into groups and comparing them to the IU of the US. He finds that the IU for metals has the form of an inverted U-shape in developed countries. While he acknowledges different growth rates for raw materials among different regions, he identifies structural forces that cause "consistencies [that] are critical to the process of future demand estimation"[132]. Specifically, he identifies the following forces behind the declining IU trend:

- Shift in economic sector composition towards less material intensive services away from manufacturing
- Technological developments that increase material efficiency along the value chain from discovery to use in end products
- Substitution

However, he qualifies his findings when he notes that a complete analysis would account for materials consumed by a country through the import of finished goods.

Several authors readily embark on this theory. Albeit not mentioning explicitly the concept of dematerialization, FISCHMAN, in a comprehensive study on global metal consumption and US supply difficulties, assumes an a priori decline of metal demand in relation to GDP in developed countries.[133] FORTIS compares the development of the US and Italy by a priori assuming the veracity of the theory. He divides the economic development and the parallel intensity of use of several materials in three development phases called "take-off", "technological maturity", and "mass consumption"[134]. While he attempts to cluster the time period between 1865 to 1990 for the US and 1946 to 1990 for Italy accordingly, it is interesting to note that he occasionally points to microeconomic developments in Italy, which revived demand for certain metals counter to the expected trend. With respect to lead, he attributes a revival of consumption to the rise of the Italian ceramics industry,[135], which implies that factors other than macroeconomic growth, dependent on country and metal industry also play a role in metal demand development.

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132 Malenbaum (1978), p.12ff.

133 Fischman (1980), p.17ff.

134 Fortis (1994), p.83

135 Fortis (1994), p.94

VAN VUUREN et al, develop a system dynamics model to estimate long-term demand and supply for thirteen world regions and assume a priori the validity of the IU hypothesis for the demand side of the model. Accordingly, they calibrate their average global demand function to result in a U-shaped global IU curve with a default "saturation level" for the metals analyzed.[136]

WERNICK et al take a more cautious approach. They argue that dematerialization has to be analyzed along the value chain and attempt to measure the effect along four stages: resource extraction, industrial manufacturing, end user consumption, and waste. Focusing on the US, they conclude that the rise of alternative materials suggests a substitution rather than dematerialization and notice that end user consumption measured by weight is by no means dematerializing. Waste appears to be dematerializing due to recycling efforts.[137]

Several authors raise fundamental critique of the theory of dematerialization. The dynamics of substitution suggest a dynamic change in metal consumption and thus in IU, which counters MALENBAUM's prognosis of a permanent decline in IU. Furthermore, the erratic nature of technological innovation as described by TILTON[138] is difficult to reconcile with apparent consistencies critical to demand estimation identified by MALENBAUM. Others voice direct criticism. One of the earliest is AUTY, who disputes findings by MALENBAUM and others on the grounds that they are ignoring the complex and often unpredictable role of innovation and substitution on demand development. He suggests that rather than witnessing a permanent long-term trend, changes in material intensity of use may be cyclical: "An alternative route to determining the direction of structural change and tracing underlying trends in materials intensity is provided by research on the long-wave economic cycles"[139].

BRINGEZU et al. analyze the material flow of EU countries, the US and China to assess the development of resource productivity. An increase in resource productivity would indicate decoupling of resource consumption and economic growth. In order to receive a comprehensive picture, they account "for all (primary) materials directly used and at the second step comprise all resource requirements of an economy in order to consider the overall effect of substitution and efficiency increase"[140]. They aggregate various materials to a number of indices and include metals in the index metals and minerals. The authors note that

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136 Van Vurren/ Strengers/ De Vries (1999), p.241ff.

137 Wernick/Herman/Govind/Ausubel (1997)

138 Tilton (1985)

139 Auty (1985), p.282

140 Bringezu/ Schütz/Steger/Baudisch (2004), p.99

this index' share of total material requirement fluctuates widely among high-income countries. With respect to a rising share of this index in Finland the authors concede that "The Finnish example shows that a development away from resource-intensive domestic supply industries towards manufacturing does not necessarily lead to a reduction of total resource requirements"[141], thus, a structural change between sectors towards intuitively less material-intensive sectors may not unilaterally reduce the metal intensity of the economy.

CLEVELAND/RUTH provide a comprehensive and exhausting overview of the work conducted to date on the topic of dematerialization. They criticize existing work on the subject on five major accounts[142]:

- Lack of statistical rigour has led many authors to make conclusions based on visual inspection of data.
- Objectionable aggregation based solely on price or weight. The authors demand that any index should account for partial substitutability of the materials.
- Failure to account for metals included in imported, finished goods. This can potentially cause two effects: the share of the manufacturing sector is sinking relative to the service sector as a product is imported and not produced domestically. At the same time, domestic consumption of raw material is reduced. While the material intensity of the importing country remains the same as before, calculating IU based only on raw material consumption may yield a declining development. This phenomenon has been termed import substitution by OPSCHOOR/REIJNDERS.[143]
- Lack of empirical evidence that services are indeed less metal intensity
- Neglect of factors offsetting dematerialization such as rising affluence and the rebound effect, which suggests a rising consumption in material that enables efficiency increases.

Focusing on the US economy, the authors conclude that there is no evidence for a decoupling of the US economy from material consumption.[144]

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141 Bringezu/ Schütz/Steger/Baudisch (2004), p.120f.

142 Cleveland/Ruth (1999), p.45

143 Opschoor/Reijnders (1991), p.14

144 Cleveland/Ruth (1999), p.1

Additional critique is voiced by LABYS, who identifies three other major short-comings of the dematerialization theory:[145]

- The time period analyzed is often covering data only till the 1970s according to the author. This is not confirmed by studies reviewed by CLEVELAND/ RUTH, which cover time periods between 1890 and 1994.
- The raw materials in focus of dematerialization theorists are only metals and industrial materials. LABYS criticizes that plastics, less common metals, and compound materials need to be considered as well.
- Ignorance of a life cycle theory, which LABYS claims covers better the demand pattern of developed economies, as technologically advanced materials are replaced for older materials.

The observation of a cyclical rather than permanent structural change initiating a long-term trend together with the highlighted short-comings of the dematerialization theory has given birth to the transmaterialization theory and the rematerialization theory, which are reviewed in the following chapter.

3.2.1.3 Transmaterialization and rematerialization

The popularity of the dematerialization theory is unmatched by other economic theories. Nonetheless, the methodological and theoretical short-comings of studies on dematerialization sparked two alternative but similar concepts, which are briefly discussed in this chapter, the transmaterialization theory and the rematerialization theory. However, few studies have investigated theses concepts further. Table 8 provides an overview of the five most relevant studies:

Author	**Findings**	**Metal sector (s)**	**Time period**
Labys/ Waddell (1989)	• Cyclical materialization suggests shift between material classes, not dematerialization	Iron, copper, lead, tin, zinc, bismuth, molybdenum, nickel, manganese, vanadium, chromium, lithium,	1885-1986

[145] Labys (2004), p.3f.

Author	Findings	Metal sector (s)	Time period
		aluminum, cobalt, gallium, hafnium, platinum, titanium, titanium, rare earth	
Humphreys (1982)	• Life cycle concept for metal demand is of little value • Changing end use applications suggest superposed or sequential cycles instead	Aluminum, molybdenum, gallium, chromium, copper, tungsten, cobalt, antimony, tin, mercury, lead	
De Bruyn/ Opschoor (1997)	• Intensity of use is N-shaped, suggesting periods of rematerialization	Steel	1960-1995
Hüttler/ Schandl/ Weisz (1999)	• Specific shape of intensity of use country specific	Aggregated material index including metals	1975-1990
De Bruyn (2002)	• Intensity of use is N-shaped, suggesting periods of rematerialization		

Table 8 – Studies on transmaterialization and rematerialization

Source: Own illustration

- **Transmaterialization**

The transmaterialization theory postulates that rather than decoupling economic growth from material consumption as suggested in the face of declining material intensity of use (IU) for some metals, "a number of material IOU [intensity of use] patterns follow the commodity life cycle theory;[…] these life cycles occur in waves"[146]. This implies that "industries continually replace old materials with newer, technologically more advanced materials"[147]. A notable and

[146] Labys/Waddell (1989), p.238

[147] Ibid.

often cited example is the rise of plastics. In this context, "Transmaterialization recognizes a recurring transformation in the way in which economic societies use materials, a process that has occurred regularly, if not cyclically, throughout history"[148]. Consequently, developed economies' needs for materials are shifting to advanced materials: "Many developed countries have thus undergone an industrial transformation in which materials basic to 20th-century society are being replaced by materials with ramifications to the 21st century"[149]. Substitution and technological change are thus explicitly considered. Nonetheless, this implies that a permanent decoupling of mature metals is possible, as more advanced composite materials replace them.

LABYS/WADDELL expand their analysis of material demand to engineered materials such as plastics and composites. They suggest that structural changes in demand explained by dematerialization is misleading and that such changes are better explained as cyclicalities. The authors argue that because these new materials tend to be lighter and more robust, the decline of materialization is inevitable. This only implies, however, the composition of materials change and that a quantity based ratio as used in IU analysis may not be a sufficient measure over time. The authors concede, however, that "To find a replacement measure is an extremely difficult task"[150]. They formulate two hypothesis which are applied to the US consumption of twenty metals and ten non-metals:

- Hypothesis 1: materials follow a life cycle with five phases comprising introduction, growth, maturity, saturation (peak in intensity of use), and decline, based on HUMPRHEYS[151]
- Hypothesis 2: life cycles for different materials occur in consecutive waves reflecting "changing economic, technological and social needs that have accompanied changing industrial development"[152]

The authors cluster the commodities in focus in five groups with group one comprising the most mature materials and group five the most modern. They conclude that both hypotheses are confirmed. For each group, a life cycle curve with a peak in intensity of use is identified. Furthermore, the peaks of these life curves occur consecutively, with each group superseding the previous group, which dematerializes after being replaced by its successor. The authors

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148 Labys/Waddell (1989), p.239

149 Labys (2004), p.6

150 Labys/Waddell (1989), p.238

151 Humphreys (1982), p.215

152 Labys/Waddell (1989), p.243

concede that their concept is entirely " technologically deterministic and does not include economic factors"[153]. This lack of consideration for economic factors, price interaction and production is also criticized by HUMPRHEYS concerning his own life cycle methodology. He concludes that the concept of a life cycle for metal commodities is of little value and suggests that given the changing end use of metals, cycles may relate to a specific application, and so cyclicality in a commodity is the result of superposing or consecutive subcycles.[154]

- **Rematerialization**

The concept of rematerialization is similar to transmaterialization insofar as it suggests that IU is not declining permanently but recovering in the period during the late 1980s, thus rematerializing after a period of dematerialization. DE BRUYN suggests that instead of MALENBAUM's U-shaped curve, intensity of use follows an N-shaped curve in the long run, implying a degree of cyclicality as the transmaterialization theory. He argues that "the phenomenon of dematerialization has often been explained by structural changes"[155] and concedes that the notion of the rising service sector at a later stage of a nation's development is indeed appealing as "citizens in developing countries first show an appetite for material welfare […] and that only at certain high income levels do services become more important.[...] Structural changes thus provide a logical explanation for an inverted U-shaped pattern of resource use"[156]. The observation of an N-shaped pattern, however, does not fit into this logic because it would imply that "consumers, in the course of economic development, start to prefer material consumption again, after a period in which they preferred more services"[157]. Plotting steel intensity of use between 1960-1995 for the UK and the Netherlands against two dimensions, the value in the current year and the value in the previous year, he observes periods in time, when IU remains relatively stable, "moving around an attractor point"[158]. At some point this equilibrium stage is distorted by "(radical) shifts in technological and institutional paradigms"[159] and intensity of use falls. This, he claims is the beginning of a phase of rematerialization: "Then the positive relationship between economic growth and materials consumption is restored and throughput rises again at approximately the same rate as the growth in incomes until a new technological or

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153 Labys/Waddell (1989), p.252

154 Humphreys (1982), p.225

155 De Bruyn (2002), p.216

156 Ibid.

157 Ibid.

158 De Bruyn (2002), p.218

159 Ibid.

institutional breakthrough enables another dematerialization phase"[160]. The author concludes that "Predictions on the future development of material use and dematerialization must take into account the stochastic imbalances in the relationship between material use and income."[161]

It remains unclear how such behavior leads to an N-shaped curve, because if during a period of rematerialization, throughput rises at the same rate as economic growth, this means that intensity of use passes through periods of stagnation before falling again. Thus, a more erratic decline rather than a gradual fall as suggested by MALENBAUM would be dominating. Nonetheless, intensity of use would still follow a permanently falling trend. HÜTTLER et al., analyzing an aggregated index of material inputs including metals and minerals for the three countries Japan, Germany and Austria suggest that dematerialization and rematerialization are dependent on a specific economy. While they identify an irreversible structural change in the dematerialization of Germany, they suggest that Japan's economy experiences cyclical delinking from and relinking into material input over time.[162]

3.2.2 Demand function estimation

The popularity of the estimation of demand functions owes to the perception that the intensity of use technique and its concept of material intensity of product and product intensity of income as the main influencing forces of material consumption next to macro-economic factors measured by GDP are insufficient to account for the complexities that influence metal consumption. Several demand models have been developed to offer an alternative approach to determine metals demand. Among the variety of different models, approaches can be broadly summarized into two categories:

- Demand-economic activity variables, sometimes considering substitute price
- Demand-price relationship models

Examples for both categories that deem relevant in the context of this study are listed in Table 9:

[160] De Bruyn (2002), p.220

[161] De Bruyn (2002), p.216ff.

[162] Hüttler/Schandl/Weisz (1999), p.29

Subcategory	**Author**	**Findings**	**Metal sector (s)**	**Time period**
Demand-economic activity variable	Suslick/ Harris (1990)	• IU-framework can be improved by adding variable for technical change, price of metal and price of substitute	Aluminum	1979-2000
	Roberts (1996)	• Demand function of economic activity variables investment, consumption and government expenditure	Aluminum, copper, lead, zinc	1950-1994
	Pei/ Tilton (1999)	• Demand is function of price, substitute price and income • Accounting for technical change and shift in consumer preferences explains elasticity of short-run demand to income	Aluminum, copper, nickel, lead, tin, zinc	1963-1992
Demand-price relationship models	Hughes (1972)	• Stable relationship between price and demand for several metals • Common metal demand function	Aluminum, copper, chrome, gold, iron, lead, niobium, nickel, platinum, silver, tin, titanium, vanadium, zinc	1972

Subcategory	Author	Findings	Metal sector (s)	Time period
	Nutting (1977)	• Relationship between metal price and demand stable over time • Common metal demand curve	s. Hughes (1972)	1977
	Jacobson/ Evans (1985)	• Relationship between metal price and demand stable over time	Tellurium, antimony, magnesium, lead, zinc, pig, iron, aluminium, cadmium, cobalt, copper, gold, mercury, nickel, selenium, silver, tin	1961-1980
	Georgentalis/ Nutting/ Phillips (1990)	• Relationship between metal price and demand stable over time • Deviations explainable by inflation and industrial activity	s. Hughes (1972)	1975-1983
	Evans/ Lewis (2002)	• Strong evidence for individual rather than common metal demand curve	s. Hughes (1972)	1980-1999

Subcategory	Author	Findings	Metal sector (s)	Time period
	Evans/ Lewis (2005)	• Each metal has individual demand function with different income elasticities of demand	Aluminum, copper, lead, nickel, zinc, iron ore, tin	1969-1999

Table 9 – Studies applying the demand function estimation methodology

Source: Own illustration

ROBERTS develops a model, which expresses global metal consumption for the metals aluminum, copper, lead, and zinc as a function of three factors (products): a) world investment expenditure, b) world personal consumption, and c) government expenditure. He reaches different levels of influence for all three factors depending on the metal. His major conclusion is that world economic activity in these tree factors serves to explain world metal consumption quite well and that material composition of product is by no means constant but experiences changes over time.[163]

SUSLICK/HARRIS attempt to estimate Brazilian aluminum consumption thirteen years into the future. They suggest that the historical fit of the U-shaped intensity of use curve can be improved by a lognormal model that considers also the price of the metal, the price of the substitute as well as technical change next to GDP. They concede, however, that technical change is impossible to measure and suggest time as an appropriate measure. Furthermore, they implicitly assume that copper is the only relevant substitute for aluminum by integrating the price of copper as the substitute price into their model.[164]

Using a similar demand model as SUSLICK/HARRIS, PEI/TILTON attempt to model the cyclicality of demand more accurately. They suggest that failure to account for technical change and shift in consumer preference is the reason behind failure to empirically verify that metal demand is elastic to changes in income in the short run. This elastic behavior would be expected as production output of metal intensive industry sectors tends to be much more cyclical than GDP and consequently, elasticity greater than one should be observable in the short-run for metal demand and income change. Using time as a variable for both technical

[163] Roberts (1996), p. 187)

[164] Suslick/Harris (1990), p.184f.

change and shift in consumer preferences, the authors conclude that for high-income countries, elasticity is much higher when the above mentioned time variable is considered. For low income countries the results are less obvious as the effect of the time variable reduces the short-run elasticity. The authors suggest that this because rising demand from increase in income is offset by a demand reducing effect from new technology.[165]

Others attempt to express metal consumption as a function of its price only. As stated by economic theory, metal consumption should respond to price changes. Accordingly, several autors, including HUGHES, NUTTING, and JACOBSON/ EVANS and GEORGENTALIS et al. estimate a relationship between the price and the global consumption of several metals that follows the relationship

$$\ln(P_{it}) = \ln(\alpha) + \beta \ln(C_{it}) \qquad (1)$$

where P_{it} is the metal price, and C_{it} is the annual global consumption.[166] $\ln(\alpha)$ is intercept value of the $\ln(P_{it)}$-axis and the (theoretical) price at which consumption would drop to zero. β is the inverse of the price elasticity of demand. Its value is a measure for the ease of substitution of one metal by another. In this model, "world supply or production is predetermined by exogenous factors such as mining conditions and economic considerations"[167]. For JACOBSON/EVANS, the parameters β and α are also time dependent. The above mentioned authors calculate this relationship for different points in time and a variety of metals (compare Table 9 for details). They make two important observations. First, the values for β appear to be similar between the different metals. Second, the values for β remain constant from year to year, which implies that metals have a common price elasticity. This leads some authors to conclude that a number of metals share a common demand curve that is stable over time.

EVANS/LEWIS (2002) and EVANS/LEWIS (2005) question the notion of a common demand curve. They state that this would imply that: "all the metals placed on it must be equally good substitutes in each of their end use markets"[168]. Furthermore, "the supply function for each metals would have to be perfectly price inelastic"[169]. They concede that

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165 Pei/Tilton (1999), p.92

166 Hughes (1972); Nutting (1977); Jacobson/Evans (1985); Georgentalis/Nutting/Phillips (1990)

167 Evans/Lewis (2002), p.97

168 Evans/Lewis (2002), p.97

169 Evans/Lewis (2005), p.58

while some metals may be substitutes for others in specific end use applications, by no means does this account for all the metals reviewed by the authors (s. Table 9). They suggest that the allegedly common demand curve is a so-called mongrel function, a mixture of a supply and demand curve put through a set of individual metal demand functions. They test this hypothesis and find evidence that each metal has its own demand curve. They conclude that while metal price and consumption still have roughly the same price elasticity of demand: "this relationship should be interpreted as a mongrel function rather than a stable common metals demand curve. The stability over time probably reflects the fact that the same type of information is averaged each year"[170]. Furthermore, the speeds of price adjustments are found to differ greatly between metals. Finally, the fact that the long run demand elasticities of all metals to industrial activity is below one except for aluminum lets the authors conclude that these metals' share of world economic output has been shrinking over time, an implicit confirmation of studies concerned with shrinking intensity of metal use in certain economies.

3.2.3 Production function estimation

The production function is somewhat less popular than the demand function or intensity of use approach. Metal demand is derived through estimating the production function of an end product or an industry, of which metal is an input factor. By expressing metal input as a function of other complementing input factors such as energy, labor, and capital or of possible substitutes for other raw materials, total metal demand of a specific application or an entire industry may be estimated. The approach is thus used primarily to analyze material substitution.[171] Table 10 contains a selection of studies from this field:

Author	Findings	Metal sector (s)	Time period
Kopp, Raymond; Smith, Kerry (1980)	• Estimation of production function for complex technology subject to far reaching assumptions	Iron ore, scrap	-

[170] Evans/Lewis (2002), p.104

[171] Tilton (1990), p.30

Author	Findings	Metal sector (s)	Time period
Slade, Margaret E. (1981)	• Production function approach has several shortcomings: • lack of dynamic change • aggregation of inputs	-	-
Choe, Boum-Jong (1989)	• IU-framework insufficient to explain structural change in demand after 1970 • Production factors capital, labor energy also needed to explain change	Metal index	1950-1985

Table 10 – Studies applying the production function methodology

Source: Own illustration

SLADE provides a review of studies on production functions. She gathers that motivation for analyzing the substitutability of metals stems primarily from concerns of short-run availability and long-term depletion concerns.[172] As major shortcomings of the production function approach she identifies the difficulty resulting from using aggregated inputs and from introducing dynamic change of elasticities between inputs. The former is inevitable to reduce the number of factorial inputs and technological processes but appears to reduce the informational value of the model considerably. Introducing dynamic change appears to be possible in very narrow market boundaries only.[173]

KOPP/SMITH's work on three different cost-minimizing models for different types of steel production processes illustrates similar shortcomings. They too define nine aggregated factor inputs, including iron ore and scrap without addressing the possible dynamics of substitution between aggregated factors. In order to be able to account for the complex substitution elasticities between factor inputs, the authors qualitatively define a "conventional practice"[174] based on experimental analysis, which they concede are specific to the features of the experiment and are difficult to extrapolate.

[172] Slade (1981), p.103

[173] Slade (1981), p.106f.

[174] Kopp/Smith (1980), p.631ff.

CHOE's study on how to explain falling metal consumption in several countries after 1974 is a direct response to TILTON's[175] early work. CHOE expresses doubt that factors such as material substitution and material-saving processes experienced an accelerated development or a structural change since the 1970s as there appear to be no grounds to conclude a drastic change.[176] He suggests that more factors are relevant than offered by the intensity of use framework and introduces a model, which includes the metal price, the labor wage rate, price of energy and the price of other materials including substitute materials. He defines structural change as a shift in the above mentioned factors of the demand model. His findings suggest that there is no compelling evidence of demand side structural change in metal consumption in the US. He further concludes that non-metal inputs, such as capital and energy, are more relevant variables for explaining structural change in metal demand than the price of the metal in focus. The substitutability and complementarity of inputs and metals and the fact that metal costs are usually small relative to non-metal inputs suggest that the latter have a strong influence on metal demand development.

3.2.4 Summary and evaluation

Scholars are largely in agreement that on a general level metal demand is to some extent influenced by

- income
- the price of the metal relative to the price of substitutes and complements
- technological change (both manufacturing technology and product improvement)
- consumer preference
- government activities in the form of national policies

as the six main determinants.[177] Differences abound regarding the exact impact and nature of the influence. With respect to the influence of an economy's income, the theory of dematerialization is widely dismissed today. Nonetheless, the fact that metal intensity of use is falling in developed countries and rising in emerging economies is undisputed. The relative price of a metal is an important variable in demand and production functions but dismissed in

175 Tilton (1985)

176 Choe (1989), p.7

177 Tilton (1992), p.47f.

some empirical analyses as much less relevant than economic theory suggests.[178] Technological change on the other hand is thought to have a much stronger influence, though its impact may only be noticeable when it occurs in revolutionary form. While examples for revolutionary technological change exist throughout the history of metals, the evolutionary, gradual change appears to be more common.[179] A change in consumer preference affecting metal consumption may often be an indirect effect of rising income and national policies.

It is noteworthy that these conclusions are for the most part drawn based on the analysis of non-ferrous metal demand. Few authors include refractory or other minor metals and if they do, their analysis is confined by several constraints.

Author	**Refractory metals covered**	**Other minor metals**	**Data/ analysis constraint**
Hughes (1972)	Chromium, niobium, titanium, vanadium,		Global scope only, world production for global consumption
Malenbaum (1978)	Manganese, chromium, cobalt, tungsten		Based on 12 global regions
Fischbaum (1980)	Chromium, cobalt, manganese		Based on 12 global regions
Humphreys (1982)	Molybdenum, chromium, tungsten, cobalt	Antimony, gallium	Global scope only, world production for global consumption
Key/Schlabach (1986)	Cobalt		Qualitative perspective only

[178] Tilton (1983), p.5

[179] Compare also chapter 3.3.2.2 on technical innovation in mining

Author	Refractory metals covered	Other minor metals	Data/ analysis constraint
Roberts (1988)	Manganese		Global scope only, world production for global consumption
Jacobson/ Evans (1988)	Cadmium, cobalt	Tellurium, antimony	Global scope only, world production for global consumption
Labys/ Waddell (1989)	Bismuth, molybdenum, manganese, vanadium, chromium, cobalt, titanium	Lithium, bismuth, gallium, hafnium, rare earth	US focus only
Ebensperger et al. (2005)		Lithium	Qualitative perspective only

Table 11 – Coverage of refractory and other minor metals in literature on metal demand
Source: Own illustration

As illustrated in Table 11, the most common constraint in analysis of refractory or other minor metals is that it is conducted on a global scale with consumption approximated by world production, lacking an economy specific analysis. The opposite constraint is a too narrow focus, mostly on the US only. A further confinement is a purely qualitative approach, lacking quantitative analysis to support hypotheses. It should be noted that the reviewed studies on metal demand provide by no means a complete overview of all studies on metal demand, a task beyond the scope of this work. The conclusion that refractory or other minor metals are underrepresented is based solely on studies reviewed in this work.

It emerges that the rigor of quantitative analysis found in most studies on non-ferrous metal demand is unmatched on the refractory metal front. Yet the demand structure of refractory metals in particular is distinctively different in many ways and it is therefore unclear, whether insights on metal demand development apply to refractory metal markets as well.

These metals are often only marginal constituents of the final product in terms of volume and cost, yet add important and indispensable functions to applications. As such, they play an important role in technical innovation. Given their small global production volume, the decision to use a certain refractory metal in a new application may have a significant impact on the entire demand structure and future demand growth. Also, substitution dynamics may differ. The decision to substitute a certain steel grade directly affects the alloying metals contained even though their price may not influence the substitution decision itself. Finally, but foremost, it is unclear whether the IU of refractory metals is indeed falling in developed countries and rising in emerging economies.

3.3 Review of literature on metal supply

The purpose of this chapter is to review academic literature on metal supply to gain a deeper understanding of the nature of market forces influencing metal supply and to develop an overview of the coverage of refractory metals.

Metal supply may stem from three general sources[180]:

- Individual primary supply
  Individual primary supply is the most common form of non-ferrous metal supply and relates to metal mined from non-renewable sources as the main product.

- Co- and by-product supply
  This form of supply stems also from non-renewable deposits but the metal is mined as a co-product or a by-product. A co-product status indicates that in order to make the mine profitable the metal must be mined together with the main product and both metals influence output. A by-product status indicates that while the metal is mined together with the main product, its total value is insignificant compared to that of the main product and consequently the by-product's price has no influence on the output.

- Secondary supply
  Secondary supply is metal recycled from scrap. Scrap may orginate from home scrap, generated in the refining phase, new scrap generated during manufacturing or old scrap, resulting from products disposed by consumers.

The supply of a particular metal may stem from all three sources and the nature of factors influencing supply may differ depending on the individual metal and the source of supply.

180 Based on Tilton (1996), p.52ff.

Yet, authors do not always distinguish between them and often refer to total supply, i.e. the sum of all sources, or differentiate between primary supply and secondary supply only. It is therefore not advisable to cluster literature on supply along the three possible sources. Rather, there appear to be three main dimensions in metal supply research, which cut across the three sources of supply:

- Long-term supply dynamics
- Short to mid-term primary supply dynamics
  - Holistic industry perspective
  - Research on the supply structure of a metal industry
- Secondary supply

Research on long-term supply and availability of resources appears to dominate literature on metal supply and the topic has lost none of its controversy over the course of decades. In fact, the recent price boom, which is the focus of this study, has renewed the debate on scarcity and depletion on the one hand and sustainable supply on the other. The topic of long-term supply dynamics are therefore reviewed in chapter 3.3.1. The dimension short to mid-term supply dynamics includes literature, which is concerned with influences often of specific nature to metals' supply industries or countries that apply over a shorter time period (chapter 3.3.2). Finally, research on recycling, albeit interwoven to some extent with sustainability of long-term supply will be discussed separately in chapter 3.3.3.

3.3.1 Research on long-term supply dynamics

While academic literature on concerns over resource availability dates back far in time, according to TILTON up to 3000 years[181], the purpose of this chapter is not to review this development but to specify underlying dynamics in long-term metal supply, which influence metal prices. In this context, two approaches to this topic stand out in academic literature, the fixed stock paradigm and the opportunity cost paradigm.[182] Table 12 contains a representative selection of studies concerned with both approaches:

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181 Tilton (2003), p.7

182 Tilton (1996), p.92f.

Subcategory	Author	Findings	Metal sector (s)	Time period
Fixed-stock paradigm	Hotelling (1931)	• Under certain modeling assumptions, prices of exhaustible commodities should rise in the future	Not specified	Not specified
	Meadows (1972)	• Collapse of industrial output due to mineral resource exhaustion	Aluminum, chromium, cobalt, copper, gold, iron, lead, manganese, mercury, molybdenum, nickel, tin, zinc, tungsten, silver, platinum	1970
	Gordon/ Graedel/ Bertram (2006)	• Providing developed world's living standard to developing world requires exploitation of all physical stock	Copper, nickel, zinc, platinum, tin, silver	1900-2000
Opportunity cost paradigm	Barnett/ Morse (1963)	• Evidence that resource scarcity is diminishing	Index of minerals	1870-1957
	Krautkraemer (1998)	• No evidence for physical resource depletion	Aluminum, iron ore, copper, nickel, lead, tin, zinc, silver	1968-1994

Subcategory	Author	Findings	Metal sector (s)	Time period
	Tilton (2003)	• Physical stock inadequate measure for assessing long-term supply • Price appropriate measure	Copper	1975-1999
	Tilton/ Lagos (2007)	• Copper shows signs of declining not increasing scarcity	Copper	Not specified

Table 12 – Studies on the long-term availability of metal supply

Source: Own illustration

- **Fixed-stock paradigm**

The above list contains by no means all studies on this topic as a comprehensive review is beyond the scale of this work. However, the recurring underlying and intuitive assumption of the fixed-stock paradigm is that against this physically fixed stock, growing demand eventually leads to physical exhaustion. Many economists argue that since the beginning of the 90s, the proponents of the fixed stock paradigm have begun to focus also on the environmental aspects of consuming non-renewable resources, a topic, which is often summarized as "sustainable development"[183]. The dominant argument that physical exhaustion is looming is thus accompanied by the notion that the current development is also environmentally harmful to future generations.[184]

In his seminal work, HOTELLING argues that under certain conditions, including a mine's fixed resource stock, mining firms because of the exhaustible nature of their assets, behave differently than firms where inputs are unconstrained over the long run. As each unit of output today reduces their revenue and profit in the future, they have to consider opportunity costs, which reflect the present value of the lost output in the future. As mineral resources are

183 Hilson/Murck (2000), p.227 define sustainable development as "the combination of enhanced socioeconomic growth and development, and improved environmental protection and pollution prevention."

184 Tilton (1996), p.91

effectively assets, they must earn a certain return rate comparable to other types of assets. If this return rate would be lower than that of comparable assets, it would pay to extract the asset and invest the resulting profits in asset with higher return rates. This would cause metal prices to decline today and increase in the future. The opposite scenario that return rates in exhaustible assets are higher than comparable assets, would cause asset owners hold on to them and reduce output. Consequently, current prices would rise and future prices fall.[185] In one of the most influential works at her time, MEADOWS forecasts a base case scenario, in which exhaustion of mineral resources lead to the collapse of per capita food and industrial output by the middle of the twenty first century. She bases this forecast on a physical measure of available metal supply against which she projects growing demand but fails to address the role of substitution and technical progress to mitigate depletion.[186] GORDON et al. take her approach a step further. They contend that the available metal stock is split into three repositories: ore in the lithosphere, metal currently in use in products, and metal contained in waste deposits. They argue that as metal consumption grows, metal is transferred from ore to products and finally to waste, where it is occasionally recycled. The relative size of these deposits serves as a measure to estimate the depletion of the ore repository. Taking a predicted figure for the world population in 2100 of 10 billion people and assuming that each person will by then have reached the per capita consumption of the average North American, they conclude that consumption would exceed the total world copper resources, thus all copper would have to be the in use repository or exist as recyclable waste.[187] Thus, the price of copper will rise and more common metals such as iron, aluminum, and magnesium will substitute for copper. Unfortunately, as is typical for the fixed-cost paradigm approach, the authors offer a point to point perspective, from a point in the past or the present to the time, when the resource will be exhausted. They provide no perspective on how this scenario will manifest, i.e. how supply and demand side will adjust in the course of time and how this will impact price other than that it will rise eventually.

- **Opportunity cost paradigm**

Advocates of the opportunity cost paradigm dismiss the fixed-cost paradigm on the grounds of several short-comings. BARNETT/MORSE in a seminal work on resource scarcity argue that previous authors proclaiming resource scarcity ignore the cost-reducing effect of

[185] Hotelling (1931). Tilton (1996) assigns Hotelling's work to a third category of long-term supply research next to the fixed-stock paradigm and the opportunity cost paradigm on the grounds that Hotelling only assumes an individual company's stock to be fixed but not explicitly assumes fixed global nonrenewable resources.

[186] Meadows (1972)

[187] Gordon/Graedel/Bertram (2007)

substitution and technical progress. They conclude that nature imposes "particular scarcity, not an inescapable general scarcity"[188]. TILTON argues that both the concept of fixed stock versus growing demand and the assumption of a known growth rate or per capita consumption in the future are flawed. He points out that metals are not destroyed when used and its recyclability is a question of cost, not availability. Furthermore, substitution opportunities may occur, which render future per capita rates useless. Third, deposits other than on this earth may be explored at some point in the future. Lastly, he argues that in any exhaustion scenario, a rising price would extinct demand before supply would be depleted. He therefore argues to use a measure to account for the opportunity cost of a resource and suggests the price as a better measure to assess whether non-renewable resources are depleting.[189] TILTON/LAGOS apply this methodology in an assessment of the long-term availability of copper and conclude that overall stable prices over the past 130 years suggest that copper deposits show no sign of depletion. However, they conclude that there are a number of uncertainties, which make a long-term projection impossible. They list several points, which can be categorized as follows: a) supply side dynamics such as innovation and technical change, recycling development, and the economics of future deposits, b) demand side dynamics such as substitution and consumer preferences.

KRAUTKRAEMER in his review of research based on the "Hotelling rule" concedes that relaxing some of HOTELLING's assumptions including the fixed stock assumption and considering a number of other factors changes his findings considerably. Furthermore, he concludes that it appears difficult to reconcile economic theory of nonrenewable resources with the empirically observed data based solely on "anticipated changes in extraction costs, interest rate, reserve discoveries, availability of backstop substitutes"[190]. He argues that accounting for factors causing unanticipated price changes is crucial but would demand much more detailed information and would have to be tailored to individual metal industries.

Literature on the topic of long-term supply availability reaches different conclusions because of the different approach to the topic. There appears to be little evidence that the recent price boom originates from physical depletion. Consequently, its origins are to be found in underlying economic, commercial, and industrial dynamics. However, neither approach to long-term availability offers any insights into the underlying drivers influencing prices. Authors usually remain on the abstract level of a point to point perspective and make no attempt to develop a deeper understanding of specific factors, which accompany cost-

[188] Barnett/Morse (1963), p.11

[189] Tilton (2003), p.23ff.

[190] Krautkraemer (1998), p. 2102f.

increasing depletion and cost-reducing technical progress, let alone offer quantification of these factors. Finally, at times of research focusing not only on long-term availability but also on issues of sustainability in metal supply[191] there is a stronger focus on non-ferrous base metals as their environmental impact exceeds that of refractory metals let alone minor metals by far given their larger volume[192].

In the following chapter, research concerned with these underlying dynamics is reviewed.

3.3.2 Research on short to mid-term primary supply dynamics

Research on metal supply, which is not concerned with a long-term perspective on availability and sustainability, can be broadly clustered into two categories:

- Holistic metal industry perspective
- Research on the supply structure of a metal industry

Studies providing a holistic industry perspective are concerned with the overall, usually global development of a metal industry. This comprises developments on the supply side but may also contain a demand side perspective as well as political and regulatory implications if relevant (chapter 3.3.2.1). Research focusing on the supply structure attempts to isolate the influence of certain factors on the structure of the metal industry (chapter 3.3.2.2).

3.3.2.1 Holistic metal industry perspective

The studies reviewed in this chapter provide a perspective on a particular metal industry. The purpose of this review is to identify specific underlying dynamics of the supply side industry, either triggered by a surge in demand or intrinsic changes within the structure of the industry, which have a long-term impact and may cause a structural change in price levels. Findings of the studies must be interpreted with respect to the state of the industry at the time of writing. Nonetheless, the type of changes that occurred provide a picture of relevant underlying forces with a long-term influence on the supply side of the metal industry. Table 13 contains a list of representative studies:

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[191] Gordon/ Tilton (2008), p.9f.

[192] Compare Exhibit 5, p.17

Author	Findings	Metal sector (s)	Time period
Fisher/ Owen (1981)	• Supply function of price, stock change, consumption and available old scrap	Aluminum	1960-1978
Mikesell (1979)	• Industry influenced by complex combination of factors • Quantitative modeling difficult	Copper	1960s-1970s
Hojman (1981)	• Primary supply mainly influenced by industrial activity	Aluminum	1967-1977
Roberts (2003)	• Structural change through increase in recycling and rising demand in China	Lead	1990-2000
Ebensperger/ Maxwell/ Moscoso (2005)	• Structural change through exploitation of low-cost deposits since 1997	Lithium	1984-2003
Crowson (2007)	• Structural change mainly due to political intervention	Copper	1945-1975

Table 13 – Studies providing a holistic metal industry perspective

Source: Own illustration

FISHER/OWEN offer a classical attempt to model the aluminum market in the US from 1960-1978 through a quantitative econometric model. Three equations are describing three sources of supply. According to the authors assumption, primary supply is dependent on the list price of refined aluminum and stock changes according to the authors. New scrap is found to be price independent and is related to consumption. Old scrap is assumed to be related to the price of aluminum and the available old scrap. Four other equations describe aggregate consumption related to price and industrial production, producer price, transaction price and scrap price.[193]

In his comprehensive review of the state of the copper industry from the perspective of the US in 1979, MIKESELL critically discusses quantitative approaches to modeling copper supply. In this context he rejects models, which attempt to express supply merely as a function of the market price as other factors, which the authors deems influential to copper supply, namely investment behavior, national policy implications such as changes in environmental policy, oligopolistic industry structure, level of vertical integration, and change in ownership are ignored. Econometric models, albeit introducing a host of other variables, fail to capture these complexities as well. E.g., he argues that the nationalization of Chilean copper assets may have altered the supply function of that country but concedes that such factors are impossible to model quantitatively.[194] The author concludes that no existing model is sufficient in capturing the complexities of the copper industry. As important influences to the global supply side of copper during the 1960s and 1970s, he identifies the following factors: a) pollution abatement regulation (impacting mostly US producers), b) nationalization of assets owned by international mining companies, c) a poor investment climate for foreign direct investment in most developing countries, d)declining concentration in the industry due to the emergence of new producers, e) competition from scrap, f) introduction of the hydrometallurgical process as a new copper producing technology. He also finds that any cartel behavior by copper supplying companies and countries was short-lived as competitive forces in the industry proved intact, e.g. the attempt of a longer-term rise in prices was followed by investment in new capacity, making it impossible to sustain higher prices over the long-term.[195]

HOJMAN raises similar critique as MIKESELL with regard to the incomplete specification of existing supply models, particularly those, which are based solely on a price-supply relationship. With respect to new developments in the market such as new entrants or discontinuities resulting from technological change, he concludes that "price movements cannot be predicted using econometric estimates"[196]. In his own supply model, the author accounts for two events leading to an unexpected reduction of supply after 1974 through the introduction of a dummy variable, namely a) the overall reduction of economic activity in OECD countries and b) the introduction of a new tax imposed by governments in major

[193] Fisher/Owen (1981), p.150ff.

[194] Mikesell (1979), p.175

[195] Mikesell (1979), p.146ff.

[196] Hojman (1981), p.88

bauxite producing countries. He suggests that in the long-run only the first factor has a significant influence on supply. According to his assumption the second is eventually offset by the installation of new capacity in lower tax countries.[197] The author concedes, however, that the time period of eleven years may be too short to reach reliable conclusions on this.

ROBERTS identifies a structural change in the supply of lead throughout the 1990s. In particular he considers three developments to be pivotal to the industry: a) the diminishing role of primary lead caused by b) the increasing role of recycled lead and c) the rise of China as a dominant supplier and consumer.[198]

EBENSPERGER et al. analyze the lithium market since 1984. The authors identify a structural change in the supply market due to the emergence of a new high volume supplier in Chile in 1997, who, by means of exploiting a different type of deposit compared to incumbent producers was able to reduce costs considerably. An aggressive pricing strategy drove prices down considerably and led to a decline of output and revenue from incumbent suppliers relying on higher-cost deposits according to the authors. Forecasting the future development of the industry, the authors suggest that given its favorable cost position and the large available resources of the Chilean market leader, a highly concentrated industry is likely in the future.[199]

CROWSON's study on the copper industry from 1945-1975 is an example of a holistic industry perspective motivated by the price development of the metal, which showed increasing prices as opposed to other non-ferrous base metals, whose prices were largely declining. His findings suggest that factors other than economic activity were influencing the industry. Supply was subject to extraordinary influences, such as political disturbances, government influenced copper allocation schemes and strategic stock piling.[200]

Studies attempting to provide a holistic picture of a metal industry largely concur that modeling metal supply through an econometric model falls short of capturing the number of factors, which are identified as influencing the supply industry in the longer term. This is because of the erratic and unpredictable nature of these factors. Nonetheless, when focusing on a particular time period, authors provide a comprehensive picture of factors influencing supply. Yet, no attempt is made to cluster and prioritize structural factors along certain general dimensions.

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197 Hojman (1981), p.91

198 Roberts (2003), p.

199 Ebensperger/Maxwell/Moscoso (2005), p.224f.

200 Crowson (2007), p.1f.

3.3.2.2 Industry supply structure

Literature reviewed in this chapter is concerned with factors influencing the supply structure of an industry. Studies focus either on a set of factors occurring in a particular metal industry or attempt to isolate the influence of a dominant factor on supply, such as government control or an oligopolistic supply structure. Given the difficulty to quantify the impact of certain factors, some studies in this chapter remain qualitative in their assessment of how industry forces influence prices. Also, the case study approach of many studies limits the transferability of findings to other metal industries. Table 14 lists a set of representative studies reviewed in this work:

Subcategory	Author	Findings	Metal sector	Time period
Overall focus on particular metal industry	Mackenzie (1981)	• Canadian copper industry competitive on global scale	Copper	1978
	De Sa (1991)	• European non-ferrous industry loses competitiveness	Non-ferrous metals	1974-1993
	Crowson (1992)	• Forces influencing metal supply rather political and economical than geological	Copper, bauxite, iron ore, gold, nickel, zinc	1960-1990
	Maxwell (1999)	• Technological change and new entries will lead to structural change in industry	Nickel	1991-1998
Specific focus on particular factor influencing supply	Koscianski/ Mathis/ (1995)	• Excess capacity effective barrier to entry	Titanium	1970-1990
	Cariola (1999)	• Development of industry hindered by endogenous entry barriers	Titanium	1980-1992
	Wårell (2007)	• Merger of leading producers was motivated by efficiency increases, not market power	Iron ore	-
	Markowski/ Radetzki (1987)	• No evidence that state ownership in mining destabilizes prices	Copper	1964-1983

Subcategory	Author	Findings	Metal sector	Time period
	Radetzki (1989)	• No evidence that public ownership in mining threatens private companies	Aluminum, copper, iron ore, tin	1960-1981
	Rami (2008)	• State owned enterprise may oversupply and destabilize market	Phosphate	1975-2005
	Bartos (2007)	• Productivity increases and innovation in mining about the same rate as manufacturing sector	-	1950-2000
	Schleich (2007)	• Energy reduction in steel processing due to revolutionary and incremental technical improvements	Steel	
	Piermartini (2004)	• Export restrictions lead to distortions in manufacturing and consumption	-	2003

Table 14 – Studies concerned with a metal industry supply structure

Source: Own illustration

CROWSON investigates changes in the geographical supply landscape of copper between 1960 and 1990 and identifies factors influencing location and competiveness changes. He then attempts to mirror these influences in the development of supply markets for six other metals. One of his most important findings is the relevance of economical and political rather than geological conditions to the development of the metal supplying industry. In this context, he identifies complacency, lack of investment and reliance on government action as the main reasons for the decline in copper US production. The unexpected rise in US copper production since 1985 after a recapitalization of the industry proves that declining ore grade and increasing cost of depletion were by no means the driving forces behind two decades of declining production according to the author. With respect to new investments in the copper industry during the time of the analysis, CROWSON notes that the larger size of new mining projects led to larger economies of scale and consequently a better cost position. Turning to bauxite the author points out another example of political forces leading to a structural change of metal supply. Political decisions in some Caribbean countries to impose taxes and control prices of bauxite fostered a shift in location and the rise of alternative sources in Australia, Brazil and Guinea. In the nickel industry, the author identifies a geographical diversification allegedly due to the unreliability of Canadian supply in the late 1960s. This triggered a wave of new projects in Australia and initiated a shift to laterite deposits.[201]

MAXWELL analyses the development of the nickel supplying industry in the 1990s. He makes out a surge in low cost new projects and predicts that this may result in a structural change of the industry. According to him, several forces impact the supply side industry. Technological change allows the development of laterite deposits, in which cobalt is often mined as a by- or co-product. The authors thus identifies the price of cobalt as a new influence to nickel production in the future. A second major influence next to technological change is the emergence of new players, mainly in Western Australia. According to the author, this may impact the existing oligopoly of incumbent suppliers, lead to a decline in the concentration of the industry and exert pressure on existing high cost projects. Finally, rising palladium prices have influenced favorably Russian production and the export of nickel. MAXWELL concludes that these structural changes seem to "confirm the downward trend in nickel prices"[202].

The impact of oligopolistic forces in the titanium industry is the focus of CARIOLA's work. She identifies endogenous variables, i.e. those resulting directly from actions of incumbent players as "main limits to its development"[203]. Her analysis matches findings of CROWSON, that political and economical rather than geological factors such as depletion are the dominant forces shaping the metal industry structure. Despite an abundance of titanium in the earth's crust according to which titanium would have to be clustered with other alloys, it is still regarded as an almost precious metal according to the author. CARIOLA claims this is because of a set of key endogenous factors limiting the development of the titanium industry, among which are lack of technical innovation regarding the process of making titanium

201 Crowson (2007), p.1ff.

202 Maxwell (1999), p.5

203 Cariola (1999), p.151

sponge, overcapacity, reliance on the aerospace industry as the key demand sectors and lack of efforts to expand into new industry sectors.

Focusing on the same industry, KOSCIANSKI/MATHIS analyze the impact of excess capacity the probability of a firm entering the US titanium industry. They conclude that the presence of excess capacity serves as an effective barrier to entry, concurring with CARIOLA that excess capacity is one of the factors limiting the development of the industry. Unfortunately, both authors remain qualitative in their assessment of how this is impacting the price of the metal.

WÅRELL's work is equally concerned with the concentration of suppliers. She analyzes stock market reactions before and after the merger of Rio Tinto and North Ltd. in the iron ore industry to assess the motivations behind the consolidation, which under the assumption that both firms intend to maximize profit may either stem from efficiency increase or market power to increase prices. She concludes that efficiency increases rather than market power was the main motive behind the merger.[204]

MARKOWSKI/RADETZKI investigate the effect of state ownership in the mining industry, specifically the claim that nationalized companies's output is insensitive to price change and thus public ownership of mining companies may lead to a destabilization of prices. Their findings suggest that this claim does not hold up. They suspect that differences in supply elasticity to price changes between private companies, which are mostly found in developed countries and publicly owned companies mostly found in developing countries stems from a lower share of variable cost in the latter. Thus, in the event of price decrease, state owned companies continue to produce as any revenue covers their fixed cost, whereas privately owned companies may find it easier to reduce their cost position significantly by reducing output and variable cost.[205]

In a case study analysis of the Jordanian phosphate industry, RAMI reaches a different conclusion. He claims that the growth of state owned enterprises since 1960 "constituted one of the major structural changes in the world mining industry"[206]. Based on the observation of that the Jordanian state owned monopolists raised output despite falling prices between 1971 and 2005, the author concludes that the main intention of the player was not profit maximization but adjustments to the national balance and the need for foreign exchange from

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204 Wårell (2007), p.191ff.

205 Markowski/Radetzki (1987), p.19ff.

206 Rami (2008), p.196

phosphate exports. He makes out a tendency by state owned enterprises to oversupply and destabilize the market.[207]

RADETZKI investigates the impact of state ownership to the industry in general and to specific companies on a more general level. He concludes that while the act of nationalization itself posed a serious threat to the private industry, the effects have worn out over time. As nationalization is found to have come to an end according to the author, public ownership ceases to be a threat. Effects such as differences in supply sensitivity to price albeit intuitively existing appear difficult to quantify.[208]

A different type of government intervention has upset global markets only recently. China as a major metal exporting country and other countries introduced export restricting measures on a wide range of metals mined and produced domestically. Such measures are not prohibited by the WTO[209] and are usually intended to achieve one or more of the following goals from the viewpoint of the exporting country[210]:

- Nuture an infant industry
- Control inflation
- Mitigate domestic prices
- Buttress government revenues
- Underpin social policy and income distribution

The levying of such export restrictions on metal commodities is relatively recent. Most notably metal exports from China are subject to export tariffs and export quotas, after a long period of rebates on exports.[211] As these exports restrictions do not apply to finished products, this gives Chinese manufacturers a raw material cost advantage over foreign manufacturers.[212] According to PIERMARTINI, who investigates export restrictions on food commodities, the welfare effects of export restricting measures introduced by a dominant exporter are such that the terms of trade of the exporting country improve whereas the terms of trade of the importing country deteriorates. Overall, export restrictions lead to distortions in

[207] Rami (2008), p.201

[208] Radetzki (1989), p.55ff.

[209] Piermartini (2004), p.2

[210] Barfield (2008) p.2

[211] Compare chapter 5.1.2 and Appendix, 9.4

[212] Schmidt-Whitley (2008) , p.1ff.

the efficiency of production as it encourages inefficient producers in the exporting country and discourages efficient ones in the importing country. The same can be said for consumption according to the author. Consumption in the exporting country may be too high, whereas consumption in the importing country may be too low as a result of the export restrictions.[213] Interestingly, despite the recent attention the topic has received in the public[214], only scarce attention appears to have been paid to it to date by scholars in the field of mineral economics.

Several authors mention technical innovation and productivity increase as the key reason why the cost increasing effects of depletion have not yet materialized. BARTOS compares the rate of innovation and productivity increases in the mining sector to that of other industry sectors. With respect to revolutionary technology triggering a structural change in the industry, the author concludes that mining has seen one to three innovations per century, about the same level as other mature industries. Productivity gains have been around 2.5 percent per year, about the same rate of manufacturing without the high-tech industry. Furthermore, he observes that with respect to investment in research and development, mining houses rely more and more on incremental improvement developed by third parties, rather than revolutionary techniques developed in-house. He concludes that there is no evidence for a slow down in productivity increases.[215]

SCHLEICH investigates technical change in the German steel industry. As BARTOS he identifies both a revolutionary structural change, a switch from basis oxygen steel to electric arc furnace, as well as incremental improvements in energy efficiency as the main drivers for a reduction in energy costs.[216]

Research concerned with factors influencing the supply structure of a metal industry is either conducted from the viewpoint of a specific industry or attempts to isolate the effect of specific factor. In the first case, a wealth of factors possibly influencing supply is named at the expense of prioritizing or clustering relevant ones and quantifying the impact of these factors in the context of structural changes in prices. Often, authors retreat to economic theory when estimating the impact on prices. In the second case, structural changes are more often quantified but isolating one particular factor is difficult and findings may be limited to a specific case.

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[213] Piermartini (2004), p.4

[214] Compare chapter 2.2, Exhibit 3

[215] Bartos (2007), p.149ff.

[216] Schleich (2007), p.109f.

3.3.3 Research on the interdependency of secondary supply and metal prices

There is a wide range of literature on secondary supply and the recycling of metals and it is beyond the scope of this work to cover it all. The review will be limited to those works, which attempt to quantify the interdependency of recycling and metal prices to develop an understanding to what extend a structural change in metal supply and a corresponding price change may originate from developments in metal recycling. Table 15 covers the relevant studies in this context:

Author	Findings	Metal sector (s)	Time period
Tilton (1999)	• Secondary production from old scrap not competitive against primary production	-	-
Henstock (1996)	• Barriers to recycling are increasing	Aluminum, copper, lead, nickel, cadmium, lead, mercury, tin, zinc, magnesium, titanium, chromium, iron, steel, cobalt, molybdenum, manganese, tungsten, rare earths	1970-1993
Roberts (2003)	• Increasing market share of secondary production	Lead	1990-2001
Gomez/ Guzman/ Tilton (2007)	• Stagnating secondary production in face of rising primary production	Copper	1966-2005

Author	Findings	Metal sector (s)	Time period
Reller/ Bublies/ Staudinger/ Oswald/ Meißner/ Allen (2009)	• Innovative products may increase dissipation of metals	Copper, iron, aluminum, nickel, tin, silver, gold, palladium, tantalum, indium	2007

Table 15 – Research concerned with the interdependency of metal recycling and metal prices

Source: Own illustration

HENSTOCK in his work on the recycling of non-ferrous metals emphasizes that "metal recycling is traditionally rooted in the economic laws of supply and demand"[217]. He notes furthermore that "Recycling has no virtue in itself. […] if it is profitable, it is done"[218]. Within these economical constraints, HENSTOCK identifies several benefits from recycling: extension of resource life, reduced material costs, energy conservation compared to primary production, reduced dependence on imports, waste reduction, availability of co-products. He defines three types of secondary material. Home scrap is generated in the smelting or refining phase and is usually reintroduced directly into the smelter or refiner or used as landfill. It is therefore highly insensitive to metal prices and its use limited by its availability. New scrap is produced during the manufacturing process, where it is collected for operational necessity and sold to scrap collectors. While its value depends on the metal price for primary material as well as its purity and composition, its collection and reintroduction as secondary material into the consumption cycle is usually insensitive to metal prices and so its use is also constrained mostly by availability. Old scrap on the other side comprises metal contained in post-use consumer goods. Collection of old scrap is usually the most costly of all three types of scrap as it is contained in products in often small traces, of unknown purity, long life time and widely dispersed. It is therefore the collection, sorting and processing cost of old scrap, which makes this type of scrap sensitive to primary metal prices. Secondary material from old scrap is therefore produced at marginal costs and thus hardly cost competitive compared with most primary sources. This fact together with the observation of real falling metal prices and increasing barriers to recycling from use of ever smaller quantities in new products and increasingly complex combination of materials makes the author wary of forecasting an

[217] Henstock (1996), p.4

[218] Henstock (1996), p.6

increasing role of secondary materials compared to primary sources. A recent study by RELLER et al. reflects the notion that new technology leads to an increasing amount of dissipated metal volume. The authors analyze different materials used in mobile phones and conclude that the recycling of spice metals, metals used only in traces in the end product but play a pivotal role due to their specific properties and functionalities, is currently not economical. This according to the authors may pose a risk for the availability of these metals in the near future.[219]

TILTON voices a similar perspective on the future role of secondary production as HENSTOCK. He rejects the notion of a bright future for metal recycling as suggested by environmentalists and other scholars.[220] While not sceptical of recycling to continue, he questions the competitiveness of recycling from old scrap against primary sources. He claims that the two events, which may increase the cost of primary production and make old scrap recycling competitive at large are increasing cost of depletion and environmental policies targeted at mining and refining. He estimates that neither appears likely in the near future, as mining companies have so far managed to counter both, increasing cost of depletion and tighter environmental regulation through efficiency increases and technological innovation, while at the same time facing real falling prices. He concludes that secondary producers may only gain market share if they manage to respond in a similar fashion. Combining this view with HENSTOCK's observation of the diverse state of the secondary industry consisting of small players compared to the rather consolidated primary industry[221], one may conclude that the latter is in a better position to innovate and raise capital to implement these innovations.

GÓMEZ et al. investigate why copper production from old scrap recycling appears to have grown much less than primary production and consumption and actually stagnated since 1996, while at the same time the availability of copper from old scrap increased. The authors conclude that one needs to distinguish between the stock of old scrap and the flow of old scrap. Only the latter appears to be used for secondary production while all copper scrap not recycled immediately ends up as old scrap stock, where it is rarely recycled.[222]

A study by ROBERTS on the supply of lead provides an example of a cost competitive secondary production. The author notes that in light of falling lead prices and falling demand due to the reduction of lead in environmentally and otherwise harmful applications, supply of

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219 Reller et al. (2009), p.127ff.

220 Tilton (1999), p.197

221 Henstock (1996), p.66f.

222 Gómez/Guzmán/Tilton (2007), p.183 ff.

lead experienced a structural change away from primary production towards secondary production. This is fostered by the fact that a major use of lead is batteries, a product relatively easy to collect and recycle. The author estimates that nearly all future demand growth will have to be supplied from secondary sources.[223]

Reviewed research on the role of recycling and their impact on metal prices is largely of the opinion that aside from home and new scrap, which is only limited by its availability, the majority of secondary production stemming from recycling of old scrap is far from cost competitive against primary production. In fact, many authors note that recycled volumes from old scrap are not keeping pace with the growth of primary production. A notable exception is lead, which has experienced a structural change in supply towards an increasing share from secondary sources. This development owes to special circumstances in the lead industry. The majority of demand for lead remains in batteries for cars, after the use of lead in dissipative applications such as fuel and paint was phased out due to tighter health regulation. For these batteries a well-established collection system exists. Furthermore, life time is relatively short and predictable and environmental regulation prohibits the disposal of car batteries as landfill.[224] These factors contribute to the rise of lead from secondary sources. The lead example emphasizes that the role of recycling depends on metal specific factors. General conclusions on the basis of metal specific case studies are therefore to be viewed with care.

3.3.4 Summary and evaluation

Across the three possible sources primary production, co-, by-production, and secondary production, a wide range of factors may influence metal supply. Pointing to six general factors, TILTON summarizes and prioritizes the diversity of influences as follows[225]:

- metal price
- input costs
- technological change
- strikes and other disruptions
- government activities

[223] Roberts (2003), p.23f.

[224] Henstock (1996), p.166

[225] Tilton (1992), p.52

- market structure

Yet to what extent these factors are indeed structural and may be the origin of a long-term influence on metal price remains unclear based on the reviewed literature. Furthermore, compared to literature on metal demand, studies on metal supply offer little guidance on how to approach the topic of supply analysis systematically. Authors are largely in agreement that myriads of factors influence supply and structural changes in the landscape of metal supply and consequently impacts on the long-term metal price may originate from any of them. As most of the studies reviewed are case examples of particular industries at certain periods in time, drawing general conclusions is difficult and findings must be treated with care. The following general insights may be extracted from literature:

- Factors influencing supply side are very much dependent on time horizon, metal industry and the geographical scope of the study.
- Political influence appears to have a large clout on metal supply given developments like nationalization of assets and establishment of export restrictions.
- The role of secondary supply is very metal specific. In general, ongoing efficiency increases in primary supply challenge the competitiveness of secondary supply. With the exception of lead, primary supply still comes at lower cost than old scrap recycling.

A structured approach to take a step back from observations specific to market and time period and trace back the influence of individual factors on the long-term metal price to consolidate them along general factors is missing.

Furthermore, few quantitative analyses are concerned with refractory or other minor metals. The coverage of these metals in the reviewed supply studies is illustrated in Table 16:

Author	**Refractory metals covered**	**Other minor metals**	**Data/ analysis constraint**
Meadows (1972)	Chromium, cobalt, manganese, molybdenum, tungsten		Fixed-stock paradigm approach, no estimation of price impact

Author	Refractory metals covered	Other minor metals	Data/ analysis constraint
Koscianski/ Mathis (1995)	Titanium		US focus only, no estimation of price impact
Henstock (1996)	Chromium, cobalt, manganese, molybdenum, titanium, tungsten,	Rare earths	Qualitative assessment of recycling, no estimation of price impact
Cariola (1999)	Titanium		No estimation of price impact
Ebensperger/ Maxwell/ Moscoso (2005)		Lithium	Qualitative assessment, no estimation of price impact
Reller et al. (2009)		Tantalum, indium	Fixed-stock paradigm approach, no estimation of price impact

Table 16 - Coverage of refractory and other minor metals in literature on metal supply
Source: Own illustration

The supply situation of refractory and other minor metals is sporadically investigated in literature on mineral economics, most commonly by authors applying the fixed stock paradigm. However, the shortcoming of this approach, namely its point-to-point perspective from today's supply and demand situation to the suspected point of depletion in the future illustrates a key shortcoming of most supply studies. The ultimate impact of an identified trend or change in metal supply on the market price or cost position is rarely estimated. Having identified a factor influencing supply, authors often retreat to economic theory such that a decrease in the concentration of supply will lower the price level.[226] Such statement, however, is rarely supported by empirical data. Also, supply characteristics specific to refractory or other minor metal markets, such as the reliance on co- and by-production sources are rarely taken into consideration.

3.4 Summary and deduction of research questions

The purpose of reviewing literature on long-term metal price development as well as metal supply and demand was to gain an understanding of underlying market forces identified to be influencing metal prices as well as to assess the coverage of refractory metal markets. Based on this review, research gaps are now evaluated and research questions deduced.

Research gap 1: Insufficient distinction of refractory and other minor metals from non-ferrous metals in economic analysis of metal markets

Conclusions and insights on the general development of metal price, supply and demand are mostly based on the analysis of non-ferrous metal markets. E.g., the relationship between the development of metal consumption and economic performance has been tested for non-ferrous metals only.[227] It is implicitly assumed that refractory and other minor metal markets follow similar development paths as non-ferrous metals. Yet a proper comparison of both groups of markets to verify or dispute this assumption is missing despite the growing economic relevance of refractory metals.

Research gap 2: No consideration of the distinct demand structure of refractory metals

It was demonstrated in chapter 2.3 that market value growth of non-ferrous base metals and refractory metals between 2001 and 2008 followed different roots. With the exception of aluminum over 80 percent of the former's growth in market value resulted from a price increase and less than 20 percent from an increase in consumption approximated by production. For refractory metals on the other hand, the latter factor attributed a more sizeable share to growth of market value on average.[228] Yet the underlying cause of refractory metal demand growth particularly during the commodity boom remains to a large extent unclear. Authors are content to accept the widely stated explanation that growth in emerging markets especially in China was the leading cause for the extraordinary boom across all metal markets

[226] E.g., Maxwell (1999)

[227] Compare chapter 3.2.1

[228] Compare chapter 2.3, Exhibit 8 and Exhibit 9

and that metal consumption relative to economic growth in advanced economies is falling. While China's role is beyond doubt, the demand structure of refractory metals is distinctively different compared to that of non-ferrous base metal markets. Whereas the former often comprise a substantial share of the total material as well as of the full cost of the end product, refractory metals are contained in often miniscule quantities in the end product and usually comprise a marginal share of total cost. Yet they are added to steel for the fundamental improvement they bring to bear. A thorough understanding of these characteristics is imperative to comprehend their influence on the demand growth of refractory metals.

Research gap 3: No quantitative analysis of demand growth of refractory metal markets

A quantitative analysis of factors influencing metal demand such as economic growth is possible up to a certain level as illustrated in several reviewed studies. Yet this quantitative investigation of metal demand growth is to date reserved for non-ferrous metals.[229] With few exceptions that are either US focused only or aggregated on a global scale, a quantitative decomposition of refractory metal demand growth has not yet been conducted. Yet such an analysis is indispensable to complement and validate an understanding of the distinctive demand structure of refractory metals and its impact on demand growth.

Research gap 4: No holistic perspective on structural forces in non-ferrous base metal and refractory metal markets affecting the long-term price level and volatility

The popularity of the stylized fact that declining ore grade and increased production cost is overcompensated by cost savings from technical innovation in mining and refining has led many to dismiss the recent price boom as a discontinuity, which will be punctuated by the installation of new capacity[230]. The implicit assumption within this concept is that changes in the structure of the market, if at all occurring, will have no persistent impact on the long-term price other than that falling or stagnating real prices will continue to prevail. Particularly in research investigating the metal supply side, changes in the structure of supply are rarely quantified, let alone traced back to their impact on price. While numerous factors potentially impacting the supply structure are listed, a concept, which prioritizes and structures these factors and their impact on price is missing.

Studies on metal prices offer few insights into underlying market forces influencing price development. While proponents of cyclicality acknowledge the important role of structural changes in metal price development, the underlying market forces influencing this

[229] E.g., Tilton (1990)

[230] Radetzki/ Eggert/ Lagos/ Lima/ Tilton (2008), p.125

phenomenon have received inadequate attention. Claims by RADETZKI based on the analysis of a metal index that only demand shocks may accompany price super cycles and that supply responses do not impact prices[231] are unrefuted as calls for a better understanding of individual metal industries[232] and specifically of structural changes on the supply side[233] are yet unanswered.

Based on these research gaps and findings from chapters 3.1, 3.2 and 3.3, the following research questions are deduced:

Research question 1: What are distinguishing elements of non-ferrous base metal markets and refractory metal markets that justify a separate examination of the latter?

Having illustrated the rising economic importance of refractory metals, it is important to verify or dispute the implicit assumption that the latter follow the same trends and patterns and have the same underlying demand and supply structure as non-ferrous metal markets. To answer this question, a comparison of both metal groups is conducted with respect to trends and patterns on the demand and supply side to elaborate the distinguishing elements between both metal groups. Where possible, factors are quantified.

Research question 2: How does the distinct demand structure of refractory metals influence the demand development of such metals?

The extraordinary development refractory metals underwent during the commodity booms necessitates a thorough understanding of underlying forces that influence the demand for these materials. As a first step it is essential to develop a perspective on the nature of demand for these metals that are used mostly in small quantities in the end product yet effectuate indispensible functions in steel and combine this perspective with major industry and consumer trends identified to rely on refractory metals.

Research question 3: How can the impact of influences related to the demand structure of refractory metals be quantified and which other factors influence refractory metal demand?

A quantitative in-depth analysis of refractory metal demand is essential to complement and validate research question 2. Answering the latter allows to identify the roots of demand growth qualitatively. Yet in order to measure the effect of identified influences, a quantitative decomposition of demand growth on a regional level is indispensable. Selecting the adequate

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231 Radetzki (2006), p.63

232 Jerret/Cuddington (2008), p.195; Roberts (2009), p.97

233 Humphreys (2009), p.104; Humphreys (2010), p.11

model to analyze demand predates such step. Furthermore, apart from influences relating to the demand structure of refractory metals, metal specific trends such as substitution dynamics as well as country specific trends such as an import or export oriented steel industry may as well influence demand pattern of an individual refractory metal. Comprehending the impact of such microtrends is essential to complement a full perspective on refractory metal demand.

Research question 4: What are the structural forces in a metal market that impact the long-term level and volatility of a metal price and which characteristics within these forces are specific to refractory metal markets?

The most recent metal price super cycle has led many pondering not only what caused it but also how metal markets will emerge from it. Particularly suggestions that prices may reach a new plateau[234] due to structural changes in metal markets imply that prices for some metals will not fall below a new floor price level. To answer calls by authors both on price cyclicality as well as long-term trends in metal markets to complement the analysis of mere price charts with industry knowledge on individual metal markets[235] and to enrich the discussion on structural changes in metal markets and their impact on the long-term level and volatility of metal prices, a framework is developed to capture the structural forces in metal markets that influence metal prices. Insights from the in-depth analysis of refractory metal markets are embedded within the structural forces identified and differentiated from non-ferrous base metal markets. Subsequently, the framework is applied to the molybdenum market to illustrate its applicability, the occurrence of structural changes in a refractory metal market, and the consequential impact on the long-term level and volatility of the molybdenum price.

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[234] Humphreys (2009), p.104; Humphreys (2010), p.11

[235] Smith (1979), p.426; Jerret/Cuddington (2008), p.195; Roberts (2009), p.97

4. Methodological and practical approach to metal market analysis

4.1 Conception of research methodology

In the preceding chapter, research questions were posed to shape and structure the direction of this work. The purpose of this chapter is to thoroughly select the methodological approach to be applied going forward. In order to analyze refractory metal demand, methodologies reviewed in chapter 3.2 are evaluated and critically considered (chapter 4.1.1). Based on literature reviewed in chapter 3.3, insights on factors influencing metal supply are transferred into universal structural forces according to their influence on metal price to deduce a satisfactory approach to analyze metal supply (chapter 4.1.2).

4.1.1 Approach to analyze metal demand

In the following chapter, methodologies for analyzing demand development are evaluated. Owing to its wide spread application in academic literature, a particular focus was laid on the intensity of use technique and the economic theories based on it (chapter 3.2.1). Furthermore, studies based on the concept of the demand function estimation (chapter 3.2.2) and the production function (chapter 3.2.3) were reviewed. Each of these approaches has its advantages and shortcomings, which justify their application depending on context and objective.

The estimation of demand functions is usually done by econometric techniques. Economists attempt to model metal demand by defining a functional relation and elasticities to macroeconomic factors such as GDP and usually the price of the metal and its substitute. As shown in chapter 3.2.2, this approach may yield more complex yet quantifiable relationships to well documented factors of economic activity[236] than the intensity of use concept, which at some level relies on qualitative assumptions. Yet the ability to quantify a functional relationship may lead to false conclusions with regards to the adequacy of such an approach. The factors causing structural changes, such as technical innovation are difficult to account for. Elasticity of factors to demand may not be constant and a functional relationship may itself change. Factors that have not been considered in one time period may have a sizeable

[236] E.g., Suslick/ Harris(1990); Pei/Tilton (1999)

influence in the next. Another practical shortcoming is that the miniscule share of cost of refractory metals in the end product may eliminate any dependency between a metal's price and the price of a substitute. [237] These considerations render the approach of estimating a valid demand function often impossible.

The production function is usually applied when assessing how metal as an input factor to production substitutes for or complements other input factors such as labor, capital and energy. Its primary focus is therefore material substitution, either from the perspective of an individual application or, more frequently, from the perspective of entire industries. This approach bears similar advantages and shortcomings as the estimation on a demand function. While allowing to express a functional, quantifiable relationship of metal demand with other factors, technical innovation and microeconomic differences between countries may alter the elasticity and functional relationship and are impossible to model through this approach.[238] Both approaches have another shortcoming in common. The very choice of the key influencing factors, which are to be included in the model is based not on empirical analysis but on economic theory and the ability to quantify such factors. For instance, the choice for including the price of a substitute in a demand or production function is based on the theoretical assumption that producers will switch once the price is persistently low enough to justify a switch. Yet other factors influence this choice as well, such as supply outlook, public and regulatory policy.[239] These factors are difficult to predict and to measure and consequently they will not find their way into demand or production functions.

The intensity of use technique on the other hand appears to be the most promising methodology to yield results satisfactory to answer the research questions posed in the preceding chapter. The step by step decomposition of metal demand change first in GDP related and IU related factors and second in material composition of product (MCP) and product composition of income (PCI) related factors is a compelling method, which allows to identify the most relevant forces systematically through a top down approach. If economic development is found to have no relevant influence on the consumption of a metal, this lack of relationship is quickly identified and attention diverted to IU related factors. As neither change in GDP nor MCP nor PCI are the ultimate causes of metal demand change, the top down approach leads to deeper-rooted underlying forces within an industry. Microeconomic factors, substitution complexities, functional demand changes and public policy influence may thus be explicitly considered. Doing this in a consistent, rigorous manner requires a

[237] Tilton (1983), p.5

[238] Tilton (1990), p.30f.

[239] Radetzki (1990), p.111

comprehensive knowledge of both the metal industry and the individual economy. Data on this level may not always be available and may need to be replaced by qualitative assumptions. Critiques point out that stopping short of decomposing metal demand development beyond GDP, MCP or PCI renders a mechanistic technique lacking economic substance.[240] However, isolating the relevant influences for demand change through this systematic approach can be of great assistance in identifying the causes of demand side structural changes. The top down approach of intensity of use technique ensures a comprehensive and exhaustive tree of relevant drivers influencing metal demand.

4.1.2 Analysis of metal supply

The purpose of the following chapter is to define universal structural forces on the metal supply side to analyze metal supply going forward. Based on the review of literature on supply in chapter 3.3 numerous factors may affect the structure of metal supply and not all of these changes may have a notable effect on the market price. To avoid pursuing numerous factors, a promising approach is to first define specific repercussions in the market perceived during the commodity price boom and then to retrace these to structural supply side forces valid across metal markets. The two dominant repercussions in metal markets were

- Elevated price level during and after a boom[241]
- Concern of supply availability, security, and price volatility[242]

A metal price stabilizing at a new floor price level, while being triggered by sustained demand, must eventually result from a change in the production cost of the marginal producer and from a change in the devolution of the cost curve[243]. Such a change originates in the cost structure of existing or newly installed capacity. Several factors are suspected to impact the long-term cost structure of existing and new capacity:

- Cost structure of new deposits (mineralogy, mine type and size, geographical remoteness, primary versus co-/ by-production)
- Changes in the cost structure of existing deposits (changes in major cost drivers such as energy)

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[240] Considine (1987)

[241] Compare chapter 2.2

[242] Compare Exhibit 3, p.13

[243] Humphreys (2010), p.11f.

- Government activity (e.g., environmental regulation)

Political and commercial risks influence supply availability and security. From the viewpoint of importing regions, supply availability and security is affected by

- Elevated regional concentration in production and trade[244]
- Concentration on company level[245]

Finally, factors suspected to influence price volatility over the long-term are a change in market organization as well as the level of supplier concentration[246]. The forces influencing the structure of supply are summarized in Exhibit 12.

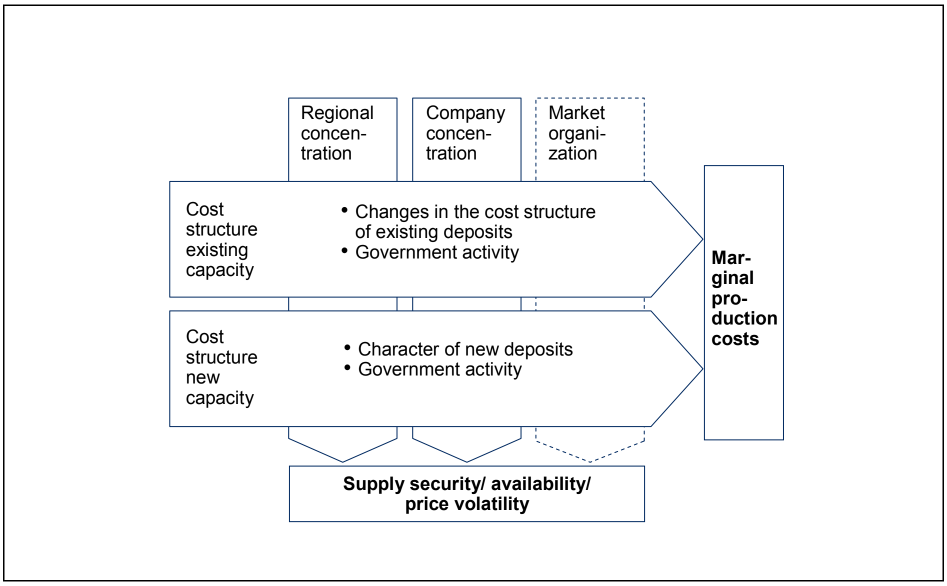

Exhibit 12 – Systematic approach to analyze structural changes in metal supply

Source: Own illustration

The column for market organization is dotted to illustrate that it is distinct from other factors as it is located at the interface of supply and demand and cannot be attributed unilaterally to the supply side[247].

Exhibit 12 depicts an ideal approach to analyze supply side structural changes. While information on regional concentration is usually available from public sources, the reliability

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[244] BDI (2006), p.43; Gordon/ Tilton (2008), p.10

[245] Gordon/ Tilton (2008), p.10

[246] Compare chapter 3.1.3

[247] Compare also chapter 7.1

of data appears to deteriorate for refractory metal markets compared to non-ferrous base metal markets as data from different sources become difficult to reconcile. Information regarding company concentration and sources of supply for a specific metal market are often proprietary or unreliable especially over a longer period of time. A perspective on company concentration is therefore excluded from the analysis going forward. Information on the cost structure of individual mines are difficult to collect and most available through proprietary sources only. Data on the cost structure of by- and co-production are usually not published at all.

In the next chapter, necessary assumptions and simplifications are evaluated based on data sources and data availability. Refractory metal markets to be covered in this work are then selected.

4.2 Data sources and data preparation

Data on non-ferrous base metal markets such as demand and supply as well as prices are usually available from public sources. As non-ferrous base metals are stock traded, global price data are published daily by metal stock exchange such as the London Metal Exchange (LME). Metallstatistik publishes regional and global historical data on primary and secondary supply as well as demand annually[248]. Production cost are often published in aggregate form in company reports and surveyed in more detail by market observers. Data from the latter are levied with some degree of accuracy but are proprietary.

In contrast, the availability and reliability of data poses a major problem when analyzing refractory metal markets, which may be one reason for the sporadic coverage in scientific literature.
Until recently, refractory metals were not exchange traded and price data are usually published in trade journals. Data on production are available from different sources but are often not congruent, underlining a lack of transparency and reliability. Data on consumption are levied by proprietary sources and are usually not published at all. When refractory metals are produced as co- or by-products, transparency on specific production cost is limited as by-producers usually do not separately account for co- or by-product cost. Even when refractory metals are mined as the main product, production cost may not be available as producers may not report them. In the following, information sources for production, consumption, price and cost data are critically discussed and constraints regarding the validity of data emphasized.[249]

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[248] World Bureau of metal statistics (2005); World Bureau of metal statistics (2009)

[249] The appendix contains detailed information on specific sources for metal and country

- **Production**

Production figures by metal and country are taken from United States Geological Survey (USGS) and are verified with data published by Raw Materials Group (RMG) and the World Mining Data Report, published by the Austrian Bundesministerium für Wirtschaft und Arbeit (BMWA)[250]. Historical and recent data on steel production are published by country by the World Steel Association. [251]

- **Consumption**

For non-ferrous base metals, consumption figures published by Metall Statistik are used. For refractory metals, most often, however, data are proprietary or not levied at all.

Therefore, apparent consumption by metal and country is estimated based on import and export figures of metals in their various forms as published by UN Comtrade. In order to calculate apparent consumption, metal import and export data must be aggregated by weight across all refined forms. This may be done through two different methodological approaches. The average metal content by form of metal import and export may be estimated using either published figures, e.g., defined metal content in a ferro-alloy, or calculations based on chemical formulas, e.g., for vanadium pentoxide, or by using USGS figures, which report gross weight as well as metal content for United States import and exports. Apparent consumption is calculated as follows:

$$C_{ijt} = P_{ijt} + I_{ijt} - E_{ijt}\left(\pm S_{ijt}\right) \qquad (1)$$

where C_{ijt} denotes apparent consumption, P_{ijt} domestic production, I_{ijt} the metal content of aggregated metal imports, E_{ijt} the metal content of aggregated metal exports and S_{ijt} producer and industry stock changes of metal i in country j in year t with

$$I_{ijt} = \sum_{k=1}^{n} I_{ijkt} \cdot c_{ik} \qquad (2)$$

$$E_{ijt} = \sum_{k=1}^{n} E_{ijkt} \cdot c_{ik} \qquad (3)$$

and

250 Weber/ Zsak (2004); Weber/ Zsak (2005); Weber/ Zsak (2006); Weber/ Zsak (2007); Weber/ Zsak (2008); Weber/ Zsak/ Reichl/ Schatz (2009)

251 Compare Appendix, 9.2

$0 \leq c_{ik} \leq 1$, where c_{ik} denotes the content of refined metal i in the form of k and I_{ijkt}, E_{ijkt} the gross weight of imports and exports of metal in the refined form k. As data on stock changes are not available, adjusting apparent consumption for stock changes is omitted. This method is based on the assumption that c_{ik} is independent of t and j, that is, constant over time and constant between countries. However, metal content may vary over time and within the same form of refined metal k. E.g., a ferro-alloy containing a specific refractory metal may be available with 20 percent of metal content as well as 40 percent. Sometimes this is country dependent as developed countries tend to import material of higher quality, usually expressed by a higher metal content. Therefore, the metal content in US gross imports and exports may not always be applicable to other countries' metal trade. In order to mitigate this effect, the aggregated weight of metal import and exports is verified using a second method. The metal content of imports and exports may be estimated calculating the specific value in USD per kg by dividing the gross weight of imports and exports by their gross value and comparing it to the annual metal price:

$$i_{ijkt} = \frac{I_{ijkt}}{VI_{ijkt}} \text{ and } e_{ijkt} = \frac{E_{ijkt}}{VE_{ijkt}} \qquad (4)$$

with VI_{ijkt}, VE_{ijkt} as the gross value of the import and export flow respectively and i_{ijkt}, e_{ijkt} the specific value of imports (exports) in USD per kg of country j and metal i in the refined form of k. Dividing the specific value of metal imports and exports by the annual metal price p_{it} yields

$$c_{ijkt} = \frac{i_{ijkt}}{p_{it}} \qquad (5)$$

with

$0 \leq c_{ijkt} \leq 1$.

c_{ijkt} is the time and country specific metal content of metal i in the refined form of k. This approach bears several caveats. It is implicitly assumed that the value of the residual material, which is not the metal in focus, is negligible. E.g., calculating c_{ijkt} for a ferro-alloy containing 40 percent of a metal compared to c_{ijkt} for a ferro-alloy containing 20 percent will only yield a difference in content of factor 2 if the value of the contained iron in the ferro-alloy is very small relative to the value of the metal. Furthermore, the difference between the published price of a metal and the specific trade value lies not only in the lower metal content of the latter. Both the specific trade value of a specific metal form and the metal price contain the value added by refining the metal. Depending on the form of refined metal, the published price may be an incorrect reference, either over- or underestimating the metal content. Finally, the value of a traded item depends on the date when the reporter invoices it. Trade flows are summarized and reported annually. Dividing annual trade flows by an annual average price may lead to a potential mismatch between the price of the metal when the trade items were invoiced and the average annual price. Both methods for aggregating the metal weight contained in imports and exports have shortcomings and may yield to different results. The decision, which value to use, may therefore not always be determined with accuracy but must also be based on informed assumptions.

Aside from these method specific considerations, further shortcomings exist. Metal specific trade flows do not account for metal contained in high strength low alloyed steel grades (HSLA), semi-finished or end products. A country, which outsources production and manufacturing of refractory metal intensive products and imports the end product reduces its domestic consumption of raw material. While the material intensity of the importing country may remain unchanged, calculating IU based only on raw material consumption may yield a declining development. Also, data on stock and stock changes are not available for refractory metals. Stock additions, which are substracted from apparent consumption in formula (1) are not recognized as such and added to apparent consumption. Ignoring stock depletions may yield very low levels of apparent consumption up to negative values, if at times industrial consumers' consumption stems entirely from depleting domestic stocks. Changes in the amplitude of metal consumption may therefore be perceived higher than they really are.

Finally, some skeptics view trade data itself as an equally unreliable source of information. While this view is not shared by the author, it is undisputed that for some countries trade data are of little use as reported data are unreliable. Furthermore, trade data never display a complete picture due to smuggling and unreported trade. Exchange rate fluctuations are not always properly recorded. As some countries do not report trade data (e.g., North Korea), one has to rely on mirror statistics, trade with the non-reporting country reported by trade partners. This may invert reporting standards by including transport, cost and insurance in exports and not in imports. Nonetheless, while trade statistics should not be the sole source of information nor accepted as ultimately precise data. Yet as by-products of custom control, they are fairly adequate and indicate an order of magnitude as well as a relative development trend.[252]

[252] International Trade Center (2005), p.1f. :http://www.intracen.org/countries/structural05/reliability03.pdf

In summary, estimated apparent consumption may differ both in magnitude and volatility from real consumption on a country level and must be interpreted with care. Depending on country and metal, this may pose serious limitations to findings. A consideration of country specific microeconomic drivers of apparent metal consumption is therefore indispensable to a interpret figures and trends correctly. As such factors are explicitly considered in the intensity of use (IU) technique[253], the above constraints for assessing metal demand further confirm the choice of the IU methodology for this work[254].

- **Price**

For non-ferrous base metals, price data are published regularly by the World Bank as well as the LME. Data on refractory metal prices are reported in trade journals such as American Metal Market, Chemical Market Reporter, Engineering and Mining Journal, Industrial Minerals, Metal Bulletin, Mining Journal, Platt's Metals Week, Roskill Information Services Ltd. commodity reports, and Ryan's Notes and published by United States Geological Survey (USGS). If no price data is available, prices are estimated based on the average value of United States import and exports of the metal.[255]

- **Production cost**

Production cost are estimated based on values reported by producing companies if available. Data constraints affect all economic analysis of metal markets. With respect to refractory metals, limitations are particularly obvious for consumption and production cost data and may be one reason for the reserved attention these markets have so far received in literature. In order to properly identify a supply side structural change behind elevated metal prices, data on production cost data of existing and new capacity as well as a perspective on the development of apparent consumption is indispensable. A view on apparent consumption and underlying drivers is furthermore necessary to conduct a proper intensity of use analysis of refractory metals and compare the demand development to non-ferrous metals. With the above mentioned caveats in mind, in the next chapter criteria are defined to refine the focus of metal markets to be analyzed in this work.

[253] Compare chapter 3.2.1

[254] Compare chapter 4.1.1

[255] Compare Appendix, 9.2 for details

4.3 Coverage of metal markets

Having assessed possible data source as well as necessary assumptions and simplifications for data preparation and data constraints in the previous chapter, the purpose of this chapter is to identify the particular refractory metal markets to be analyzed further in this work. Given the large number of refractory metals[256] confining the assessment of this heterogeneous group of metals is essential to refine the scope of this work.

The criteria to refine the group of refractory metals should reflect the approach to the topic laid out so far in this work. Accordingly, the following criteria are used:

- **Growth in market value**
  The particular focus on refractory metal markets distinguished from non-ferrous base metal markets is justified based on the observation that the economic relevance of certain refractory metals has grown remarkably during the commodity boom[257]. An important selection criterion is therefore the economic relevance of a metal, measured by market value.

- **Uniform demand structure**
  After assessing several scientific concepts to analyze metal demand, the intensity of use technique was chosen due to its compelling top down approach and the quantitative results it yields up to the level of product composition of income (PCI) and material composition of product (MCP).[258] However, due to lack of sufficient granularity of consumption data, estimating these variables is only possible if the major application of the metal is in one particular product, whose production output is publicly reported by country.

- **Data availability**
  As discussed in the previous chapter, data on apparent consumption of refractory metals globally and by country are most often proprietary and have to be estimated based on trade data. The availability of trade data at a granular enough level is therefore a prerequisite for a reliable estimate of apparent consumption.

- **Plausibility of estimates**
  As a next step, reconciling such estimates is often difficult as no officially accepted or

[256] Compare chapter 2.1, Exhibit 1

[257] Compare chapter 2.3

[258] Compare chapter 3.2.1, Exhibit 11

available source exists. However, the plausibility of estimates can sometimes be challenged through figures published by industry sources, e.g., annual reports, by matching aggregated figures such as global supply and demand as well as through industry knowledge. Nevertheless, the degree of reconciliation may vary and uncertainties remain. A metal whose estimated apparent consumption figures by country appear implausible as they grossly diverge from other sources is excluded from further analysis.

Exhibit 13 provides an evaluation of refractory metals along the above presented criteria:

	Refractory metals							
	Chro-mium	Manga-nese	Molyb-denum	Nio-bium	Vana-dium	Tung-sten	Co-balt	Tita-nium*
Growth in market value	++	++	+++	++	+++	++	++	++
Uniform demand structure	+++	+++	+++	+++	+++	–	–	–
Data availability	+++	+++	+++	++	+	–	–	n/a
Plausibility of estimates	+	+	++	++	–	–	–	n/a
	Metals chosen for further quantitative analysis							

+++ : Fully satisfactory   ++ : Satisfactory   + : Somewhat satisfactory
- : Not satisfactory

* Titanium metal

Exhibit 13 – Assessment of refractory metals by selection criteria

Source: Own illustration

Based on these selection criteria, chromium, manganese, molybdenum and niobium are chosen for further demand side analysis. In the following subchapters, the assessment along the criteria is explained.

4.3.1 Growth in market value

It has been shown in chapter 2.3 that the group of refractory metals featured the strongest growth in real market value between 2001 and 2008. During this period, the market value of refractory metals as a group grew by 33 percent annually, whereas other minor metals grew only by 13 percent.[259] This extraordinary growth since 2001 underlines the rising economic importance of these metals and makes a comprehension of the underlying factors driving this development imperative. Growth in market value is therefore chosen as a selection criteria to take into account the rising economic importance of a refractory metal.

Exhibit 14 shows the average market value from 2001 to 2008 as well as the annualized three year moving average growth rates for the periods 1980 to 2001 and 2001 to 2008 for refractory metals.

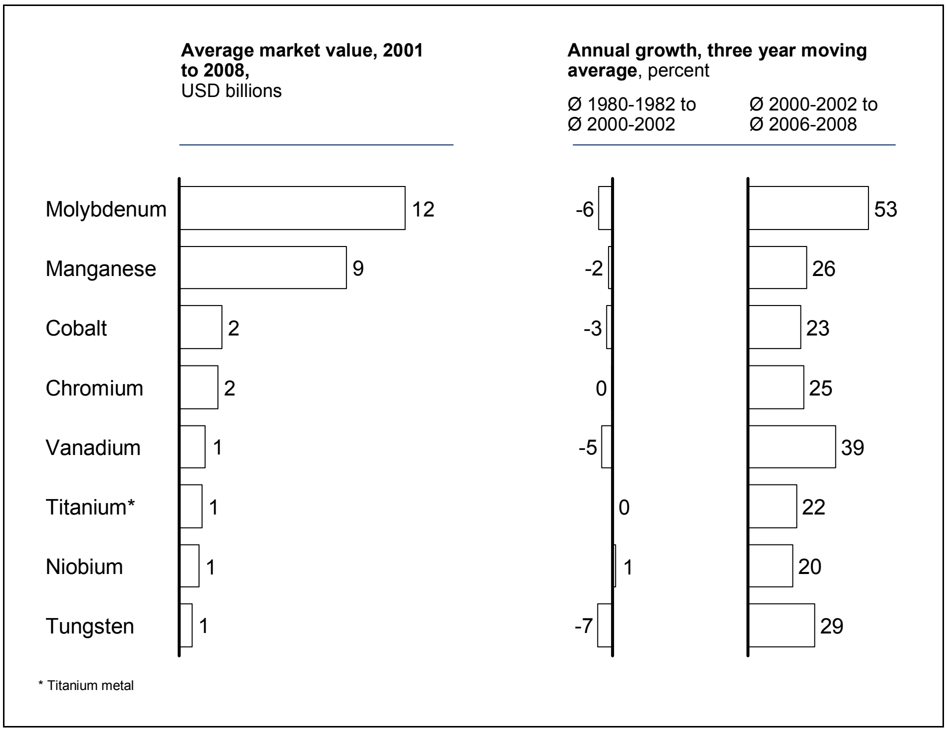

Exhibit 14 – Average market value and growth refractory metals
Source: Own illustration

The exhibit illustrates significant differences in market size. Molybdenum and manganese were by far the largest markets with 12 and 9 billion US dollars on average between 2001 and 2008. All other markets were between 1 and 2 billion US dollars during the same time period, the market for tungsten was an estimated 600 million USD. Preceding the strong growth rates between 2001 and 2008 was a two decade long period of falling or stagnating market value for all refractory metals. By far the strongest growth rates during the boom period are found in the markets for molybdenum and vanadium followed by growth rates above 20 percent for all other markets.

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[259] Compare 2.3, Exhibit 6

4.3.2 Uniform demand structure

As the majority of refractory metals is predominantly used as an alloying element in steel, steel production is the uniform application of choice. Steel production is well reported and data are published by official source.[260] The following exhibits list the demand structure of the 8 refractory metals.

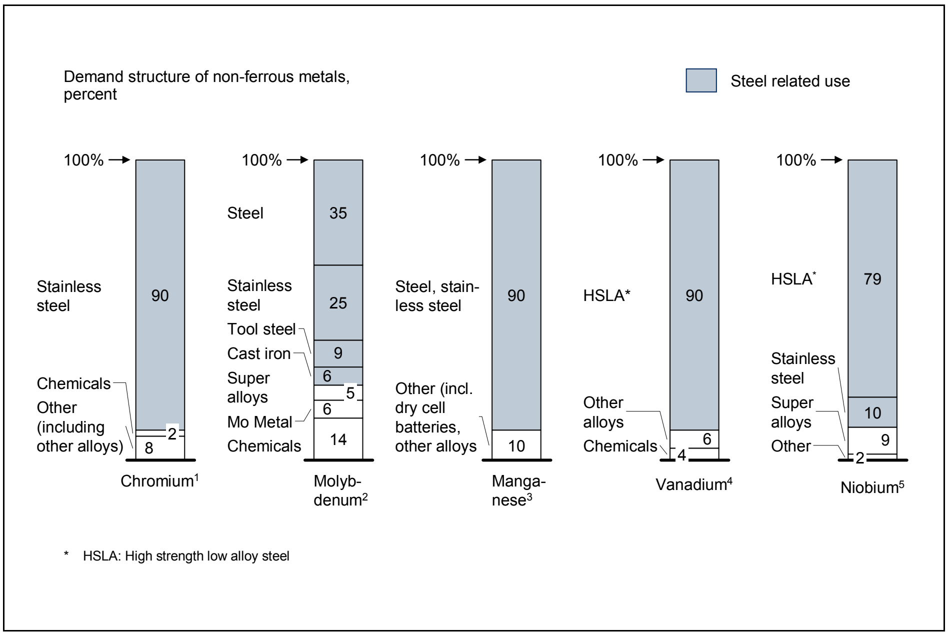

Exhibit 15 – Demand structure of refractory metals predominantly used as alloys in steel

Source: Own illustration[261]

The refractory metals in Exhibit 15 are predominantly used as an alloying element in steel, usually high strength low alloy (HSLA) grades or in stainless steel. Other minor applications are super alloys, which usually exhibit excellent mechanical strength especially at high temperatures. They are usually iron, nickel, copper or cobalt based and have a much higher content of alloying elements than HSLA steel grades. They are used for critical applications

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[260] Steel production by type is published by worldsteel.org

[261] Chromium: International Chromium Development Association (ICDA) (2010); Molybdenum: International Molybdenum Association (IMoA) (2010); Manganese: International Manganese Institute (IMnI) (2010); Vanadium: USGS (2008zm); Niobium: Companhia Brasileira de Metalurgia e Mineração (CBMM) (2010a). The exact base year for the demand structure is not always clear from the source.

such as jet engines and turbines. Furthermore, refractory metal derivates are used as chemicals.[262]

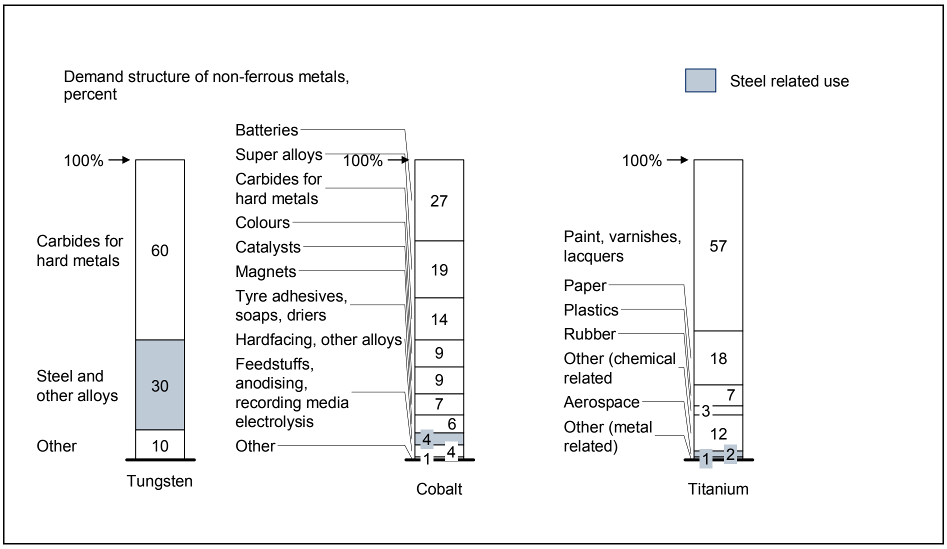

Exhibit 16 – Demand structure of other refractory metals

Source: Own illustration[263]

The demand structure of tungsten, cobalt and titanium is depicted in Exhibit 16. As illustrated, the steel related use comprises only a minor share of total demand for all 3 metals. Tungsten's major use is in the form of cemented carbides, which in combination with a binding material, usually cobalt, is pressed to form hard metals. Hard metals have a much higher wear resistance than high speed steel, which is made by adding certain alloying elements to steel.
Cobalt is used in a variety of industries. The dominant use is in cobalt-based batteries, followed super alloys and hard metals, colorings, chemicals and electronics. Only a small amount is steel related, in the form of high speed steel. Titanium's major use is in paint as titanium oxides, providing white coloring. Further applications are paper, rubber and other chemical related usage. Only a small amount is converted to titanium sponge metal, which is used predominantly in aerospace applications and other alloys.

While all refractory metals have a variety of end use applications chromium, molybdenum, manganese, niobium and vanadium fulfill their functionalities in the end product through their alloying properties in steel and stainless steel. The concentration development of these metals in steel, measured as material composition of income therefore yields quantitative information

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[262] A more detailed overview of the specific use by metal is given in chapters 6.3 to 6.6

[263] Tungsten: International Tungsten Industry Association (ITIA) (2010); Cobalt: Cobalt Development Institute (2010)

as to how the demand for these functionalities develops over time. Such a quantitative assessment is not possible for tungsten, cobalt and titanium as the granularity of data on consumption development by end use is not available or proprietary data.

The uniform character of the five refractory metals depicted in Exhibit 15 thus provides an adequate opportunity for an in-depth quantitative analysis.

4.3.3 Data availability

Whereas data on production and price are usually available for most metal types, whether or not apparent consumption may be calculated depends also on reported metal trade. Trade of goods is classified in the Harmonized Commodity Description and Coding System (HS). The latest revision is HS 2007.[264] The HS has a nomenclature of up to 10 digits, but UN Comtrade publishes trade statistics only up to six digits. This means that some trade flows are aggregated up to a level where a proper dissemination is not possible. E.g., in HS 2007, the numerical code 811292 summarizes trade of germanium, vanadium, gallium, hafnium, indium, niobium (columbium), rhenium, and articles of these metals, incl. waste and scrap, powder and unwrought. If a relevant share of either of these metals is in the form of waste and scrap, powder or unwrought metal, a calculation of apparent consumption is not possible as these forms of trade are not reported separately at the most granular reporting level. Refractory metals are usually traded in several refined forms. Table 17 provides and overview on the availability of data for all refractory metals by category[265].

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[264] World Customs Organizaton (2010)

[265] Compare Appendix, Table 19 for details

Refractory metal	Ores, concentrates, ash or residues	Chemical	Ferro-alloys	Metal	Waste and scrap	Not available/aggregated with other metals
Chromium	x	x	x	x	x	Chromium contained in ashes, slag not reported separately
Manganese	x	x	x	x		Manganese waste and scrap not reported separately
Molybdenum	x	x	x	x	x	
Niobium			x			Ores and concentrates, articles, waste, scrap and niobium oxide not reported separately
Vanadium		x	x	x (only reported in HS 1996)		Ores and concentrates, vanadium sulfates, vanadates, vanadium contained in aluminum master alloys not reported separately, vanadium contained in ashes, residues only reported till 2001
Tungsten	x	x	x	x	x	Tungsten oxide, tungsten carbide not reported separately
Titanium	x	x	x	x	x	
Cobalt	x	x		x	x	Cobalt chlorides, sulfates, carbonates, acetates not reported separately

Table 17 – Reported depth of trade by metal, HS code and description

Source: Own illustration

As can be seen from the column on the very right in Table 17, data on the trade of several goods containing refractory metals are not available. Whether or not this impedes a reliable calculation of apparent consumption depends on the share of metal contained in the trade of such goods. This in turn depends on the demand structure of the metal and the trade mix of the individual reporting country.

Chromium's major use is in stainless steel and consequently chromium is traded predominantly in the form of ferro-chromium. Only a negligible share of chromium is traded in the form of chromium contained in slag.[266] Thus, estimating chromium demand without the trade data on listed in the very right column in Table 17 is unlikely to produce a large margin of error. Data on molybdenum and manganese in their intermediate forms are to a large extent complete.

Mined niobium is reported to be predominantly converted into ferro-niobium[267]. According to the US Geological Survey (USGS), Brazil, the major producer of niobium worldwide, ceased to export niobium in its mineral form pyrochlore in 1981[268] to nuture a downstream industry of niobium containing value added products. Ferro-niobium trade data therefore appear to capture most of niobium content traded in its non-alloyed form.

Vanadium is traded in the form of ferro-alloys to be used in the production of steel, stainless steel and super alloys with only a small amount of global consumption going into applications for which other intermediate products such as vanadates and vanadium sulfates are processed[269]. Trade of vanadium contained in ashes and residues, which is reported sporadically until 2001, comprises only a marginal share of the value of total vanadium trade:

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[266] According to the International Chromium Development Association (ICDA), 95% of world production of chromite was smelted into ferro-chromium in 2008. ICDA (2010). In the same year, the split of chromium reported exports value was 71.3 percent ferro-chromium, 18.4 percent ores and concentrates, 7% chromium metal and 3.4 percent chromium oxides. The value of chromium contained in slag, reported together with other metals was less than 1%.

[267] Tantalum-Niobium International Study Center (TIC) (2010)

[268] Jones/Cunningham (1981), p.271

[269] Compare 4.3.2, Exhibit 15

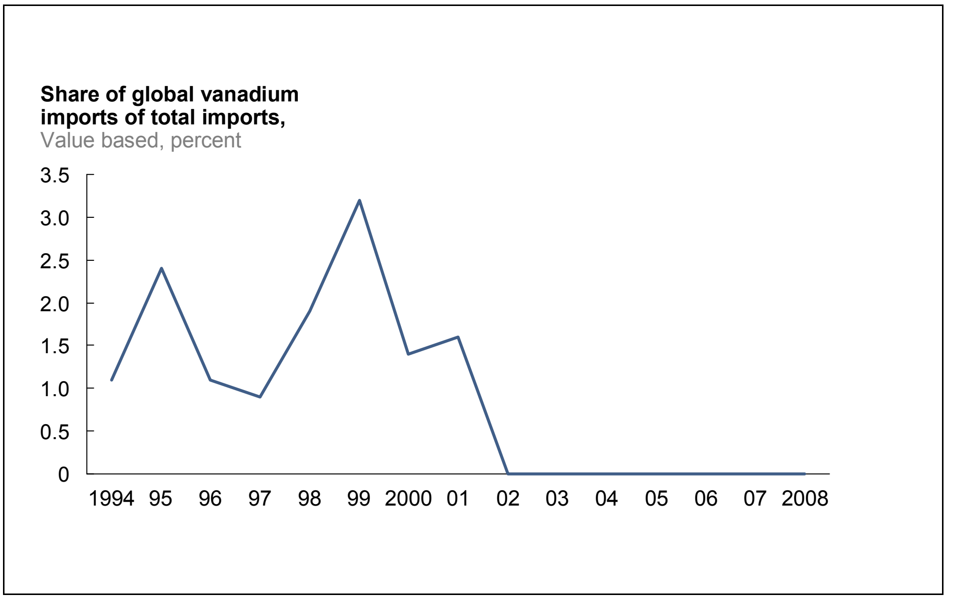

Exhibit 17 – Global vanadium imports contained in ashes and residues, 1994 to 2008

Source: Own illustration, based on UN Comtrade[270]

However, a different picture emerges for country specific trade. USGS reports values of US specific metal trade. The following exhibits contains estimated share of vanadium contained in ashes and residues of total US vanadium imports:

[270] Compare Appendix, Table 43

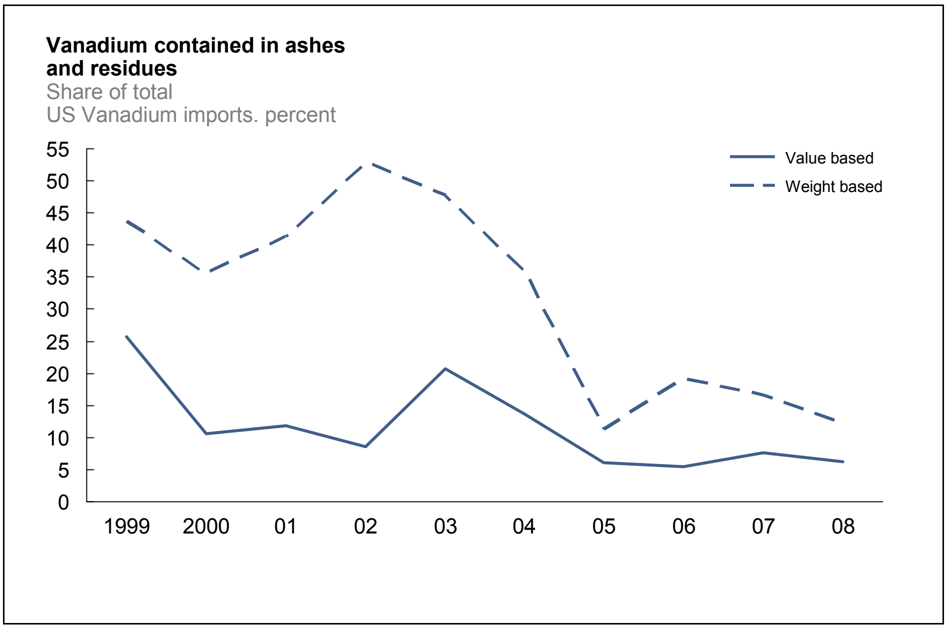

Exhibit 18 – US imports of vanadium contained in ashes and residues, 1999 to 2008

Source: Own illustration, based on USGS[271]

USGS estimates that between 1998 and 2004 around 50 percent of US imported vanadium volume was contained in ashes and residues. After 2004 imports dropped but remained over 15 percent till 2008. Based on value, the imports' share of vanadium contained in ashes and residues were much lower but remained over 5 percent in 2008.

Unfortunately, such granular data do not exist for other countries. However, Exhibit 18 illustrates that omitting trade of vanadium contained in ashes and residues from 2001 onwards in the calculation of apparent consumption may result in a potentially large margin of error for selected countries.

Tungsten's major use is in hard metals, also called cemented carbides. According to the International Tungsten Industry Association, between 48 percent of local consumption in China and 72 percent of local consumption in Europe were used in the production of cemented carbides in 2008.[272] Therefore, a significant share of tungsten trade is presumably in carbides. As trade in tungsten carbides is reported together with trade in boron carbides, aluminum, chromium, molybdenum, vanadium, tantalum, titanium and other carbides[273], accounting for tungsten in carbides is not possible and a potentially large share of tungsten

[271] Years 1998 to 2002: USGS (2002c), p.81; 2003 to 2007: USGS (2007b), p.80; 2008: USGS (2008k), p. 80

[272] International Tungsten Industry Association (ITIA) (2010)

[273] HS 2007 code 284990

consumption is exempt from the calculation of apparent consumption based on UN comtrade data.
Regarding cobalt, cobalt chlorides, sulfates, carbonates, and acetates, the intermediate forms not reported by UN Comtrade comprised 6 and 14 percent of US imports in 2007 and 2008 respectively by weight of cobalt content and about 6 percent by value, according to USGS.[274] Titanium is largely reported in its intermediate forms.

4.3.4 Plausibility of estimates

Assessing whether calculated data are plausible is often based on informed assumptions and triangulation of selected data points for which data exist as well as conversations with industry experts. Due to lack of a uniform demand structure for tungsten, titanium, and cobalt and because of a potentially large margin of error for tungsten apparent consumption for omitting trade in tungsten carbides, the metals are exempted from further demand side assessment. Nonetheless, an attempt was made to calculate demand data for cobalt, which can be found in the appendix. However, aggregated global apparent consumption could not be reconciled with reported global production.[275]

In the case of vanadium, estimates for apparent consumption could not be reconciled with values reported in conference papers and those published by Vanitec. E.g., based on the calculation of apparent consumption as described in chapter 4.2, vanadium concentration per ton of produced steel was estimated to have fallen in China from 1994 to 2008, an observation that could not be confirmed by an industry source. Based on the same source, global production figures as well as production in China and South Africa could not be reconciled with figures published by USGS.[276]

No evidence was found for significant implausibilities of estimates for chromium, manganese, molybdenum, and niobium. However, it should be reemphasized that while the granularity of trade data on these four metals in their intermediate forms is sufficient as outlined in Table 17, metal is also contained in traces in alloyed steel or in final products, which may be imported or exported. Yet, capturing the metal content in this indirect form of trade is difficult due to lack of data. Therefore, results and conclusions based on calculated apparent consumption have to be interpreted with care.

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[274] USGS (2008zo), Appendix

[275] Compare Appendix, 9.3.5 for details. The Cobalt Development Institute states that quantification of collected figures including trade and supply to calculate demand is "most difficult as figures based on official reports are lower than actual figures." CDI (2010), p.56

[276] Bunting (2009) . Compare Appendix, 9.2

4.3.5 Summary

Having dicussed the growing importance of refractory metals, their lack of coverage in scientific literature as well as a scientific approach to analyze these metal markets going forward in previous chapters, the purpose of this chapter was to assess the lack of reliable market data for these metals as well as a practical approach to levy solid information nonetheless.

Whereas data on production and price are available at large, apparent consumption has to be estimated based on published trade data. As these data do not provide information on the actual metal content of import and exports, the amount of metal contained by produced form has to be estimated. Furthermore, data on production cost are to a large extent proprietary and only rarely published by producers.

Based on mainly on the data impediments on the demand side and reflecting the choice of the intensity of use technique to analyze patterns in apparent consumption, a set of criteria was defined to assess which metal markets can be sufficiently analyzed going forward. Based on these criteria, chromium, manganese, molybdenum and niobium were found to meet all requirements for a sufficient analysis.

Given that data impediments exist mainly on the demand side, structural supply side differences will nonetheless be compared for all refractory metals in the following chapter. However, a comprehensive assessment comprising relevant influencing factors not only on the supply but also on the demand side is developed for chromium, manganese, molybdenum and niobium only.

5. Structural differences between non-ferrous base and refractory metal markets

As deduced in chapter 3.4, economic analyses of metal markets and conclusions drawn with respect to underlying market forces influencing demand, supply and price are predominantly based on non-ferrous base metal markets. It is implicitly assumed that refractory metal markets follow similar development patterns as non-ferrous metals. In light of their rising economic importance and in the absence of a proper comparison of the underlying market structure of the two metal groups, in the following chapter the supply and demand structure of refractory metals and non-ferrous metals are compared.

5.1 Structural supply side differences

In the following chapter, the supply structure of refractory metals and non-ferrous metals are compared along the factors production concentration, trade concentration and supply source as outlined in vertical columns in Exhibit 12. Changes in the production costs of the marginal supplier will be elaborated for selected markets in chapter 8.

5.1.1 Regional mine production concentration

On average, the production of refractory metals is subject to a higher regional concentration than the production of non-ferrous base metals. A common index to measure the concentration of production is the so-called Herfindahl-Hirschman Index (HHI)[277]. It is a widely used measure to determine if a market is critically concentrated. E.g., in the US antitrust law, a market with a HHI value above 1,800 is considered to be concentrated.[278] The HHI is measured as the sum of the squared market shares multiplied by 10,000. The same methodology may be used to determine the global production concentration in metal markets. Exhibit 19 shows the HHI for non-ferrous base and refractory metals for 1990 and 2007[279]:

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[277] Herfindahl (1974)

[278] US Department of Justice (2010)

[279] Production figures for 2008 in a sufficiently disaggregated form were not available by the time of writing.

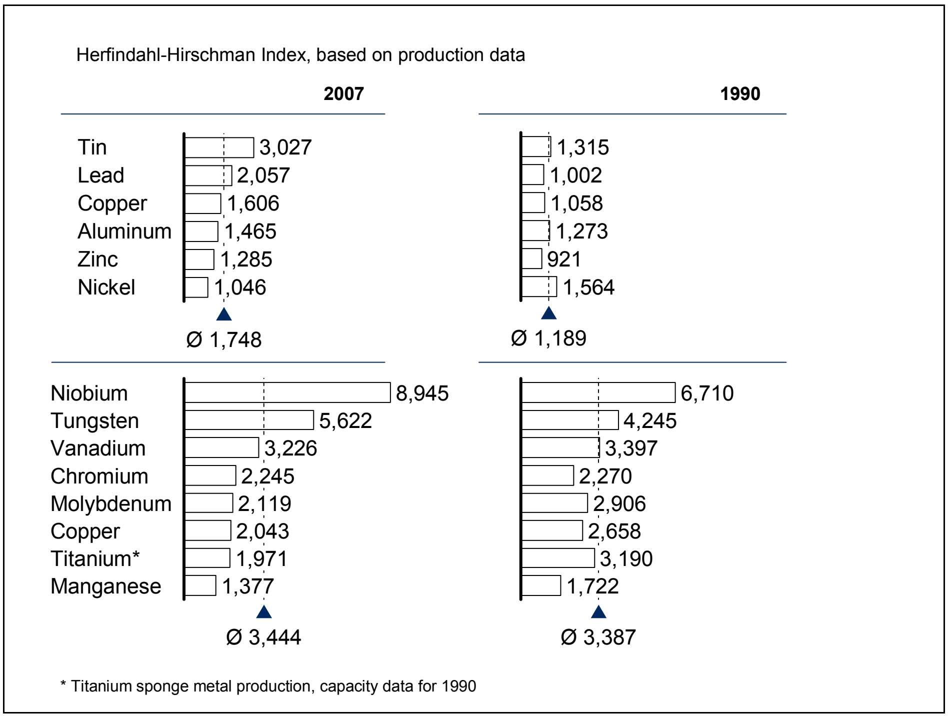

Exhibit 19 – Herfindahl-Hirschman Index (HHI) for metals, based on global production data

Source: Own illustration

As shown in Exhibit 19, the average HHI for non-ferrous metals is 1,748, slightly below 1,800, marking the threshold value beyond which a market concentration is considered critical. The HHI for nickel, aluminium, zinc and copper are below 1,800, and lead and tin are clearly above the threshold. The average HHI for refractory metals is 3,444, twice as high as for non-ferrous base metals. Only the index of manganese is below the threshold value, all other refractory metals are above 1,800. Comparing the concentration of global production in 2007 with earlier periods illustrates a gradual change in production concentration for non-ferrous metals. In 1990, the average HHI for non-ferrous metals was 1,189, below its 2007 value. Since 1990, the production concentration of all six metals except nickel has risen. For refractory metals, the average HHI value in 1990 is similar to the 2007 level. The rising concentration of niobium and tungsten was offset by falling concentration in manganese, molybdenum, vanadium, cobalt, and titanium metal. For chromium, the concentration did not change.

These findings illustrate that the supply structure of refractory metals differs from non-ferrous metals insofar as regional production of refractory metals is more highly concentrated on average and for most refractory metals. This influences supply security considerations as consuming regions are dependent on few supplying countries with fewer option to diversify their supply. The fact that the HHI for five refractory metals has fallen since 1990 may be interpreted as a reaction to concerns of supply security as production has become more diversified on a regional level.

However, the index has several shortcomings. It does not account for the reliability and openness to trade of a nation, which impedes developing a realistic perspective on the criticality of the concentration. E.g., Brazil is the dominant exporter of niobium. Niobium supply concentration with an HHI of almost 9,000 may be interpreted as highly critical, yet supply security is unchallenged as long as Brazil is a reliable trading partner. Also, assessing the production volume is misleading as a country may not export all of it or in different forms. Furthermore, countries such as China install capacities to refine certain metals that exceed the capacity needed for domestically mined ore in order to process imported ores and concentrates from countries that do not refine it themselves. Through national policies such countries may then control a large share of the refined metal globally even so the country is not a large producer of primary ore. Such constellation greatly influences global availability of certain metals but it is not captured by a production based HHI.

5.1.2 Trade concentration, export restrictiveness, and market organization

While other considerations such as mine concentration, reliability of logistics and general stability of country also play a role when assessing metal supply security, concerns over resource security during the boom were especially sparked by Chinese export restrictions imposed on metals in various forms during the commodity boom as illustrated by the countermeasures launched by importing regions[280]. The reason for this is that the introduction of national trade policies in China in 2006 and 2007, a major supplier and dominant consumer of metal commodities, which may have been intended to protect domestic assets but favors domestic metal manufacturers challenged the hitherto prevalent perception that free trade and globalization had gradually eliminated domestic access to raw materials as a competitive edge[281]. In the following the impact of Chinese trade restrictions[282] are therefore assessed.

[280] Compare chapter 2.2

[281] Porter/Baldwin (1986), p.4

[282] The focus is on Chinese export restrictions may be justified as they are the most influential in terms of trade volume affected and the most far reaching in terms of metals covered.

Measuring the supply side concentration based on trade differs from basing it on production. Whereas the country producing, i.e. mining, the ore is the origin of the metal, an ore or concentrate may be exported, refined, and exported again. By taking the value of gross exports of metals across all intermediate forms as the basis for calculating trade concentration, volume exported several times in different forms may be double counted. Exports may then appear more diversified than production and consequently, the HHI may actually be lower than if based on production. To avoid this, trade can be viewed separately for different parts of the value chain. As already illustrated in chapter 4.3.3, Table 17 metals in their intermediate forms are usually categorized between ores and concentrates, chemicals, ferro-alloys and other articles such as the pure, unwrought metal, plates, sheets etc. One then receives one HHI for each intermediate product, which may be summarized as the trade value weighted average. However, metals in different intermediates forms may still be converted into semi-products within a category, so double counting cannot be avoided. E.g., the HS code 76 comprises among other forms of aluminum trade aluminum sheets, plates, and strips in various forms (HS 760611 to HS 760692), of which aluminum pipes, tubes, and other structures and products (HS 7608 to HS 7616) are manufactured.

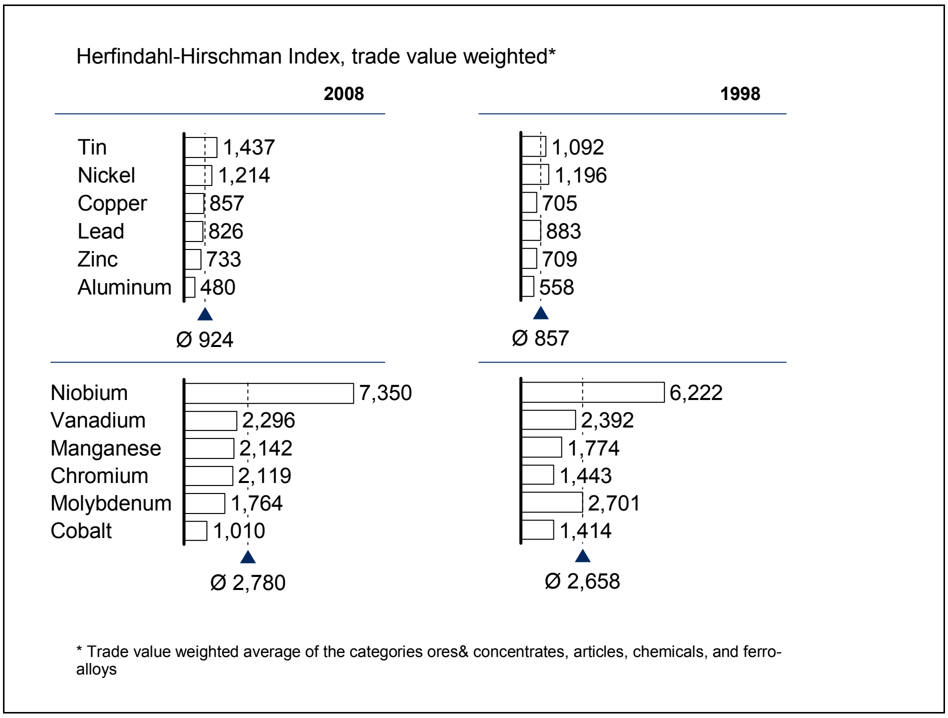

Exhibit 20 – Herfindahl-Hirschman Index (HHI) for metals, based on global trade data

Source: Own illustration

The above exhibit depicts the trade value weighted average HHI for six non-ferrous base and six refractory metals for the years 1998 and 2008[283]. Concentration shows a slight increase for both metal groups. However, the average value for refractory metals is three times higher than for non-ferrous base metals. Without niobium, the average HHI of the refractory metals depicted above is still close to 2,000, twice as high as refractory metals, which confirms and emphasizes the generally higher concentrations of both metal groups.

As with production concentration, a high export value based HHI itself says little about whether supply security is at risk as it does not contain information about the reliability of the trading partner. The latter may be captured quantitatively by assessing policy measures towards restricting trade. The most commonly used index to account for trade restrictiveness, the IMF's trade restrictiveness index, is a very broad measure, spanning the entire trade of a nation not just trade in metals and predominantly accounts for import bound tariffs. Yet risk to supply security inherently stems from the restriction of exports of certain raw materials in various forms.

In order to capture how much the export of a metal is restricted relative to global trade, export tariffs therefore appear to be the appropriate measure. Given that China is the major supplying economy levying export tariffs, the focus is on tariffs from China. The caveat of this approach is that export tariffs are subject to national policy and may change according to the political and economical environment. Also, they are designed to influence exports, which are then also exposed to more volatility than production levels. Therefore, it can be argued that a one year analysis of both export concentration and export restrictiveness based on export tariff may be of little informative value going forward. However, the fact that China did not alter most of its metal export tariffs in 2009, the year, in which metal markets were hit particularly hard by a global recession, suggests that rather than being temporary tools adaptable to global demand, these tariffs are there to stay. Furthermore, in order to account for any short-term reactions these surcharges may have triggered on the side of importers, such as switching to suppliers from other nations as far as possible, 2008 instead of 2006 or 2007, the years in which most export tariffs were introduced, is chosen to not overstate the influence of Chinese export restrictions.

[283] 1998 instead of 1990 as for production was chosen to receive a more complete set of trade data.

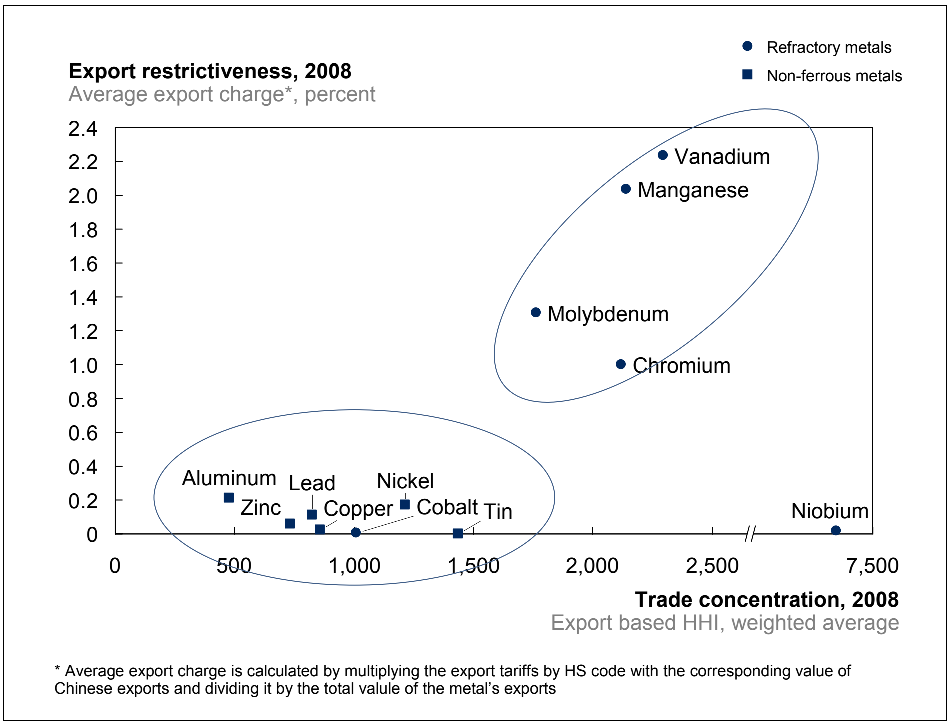

Exhibit 21 – Trade concentration and export restrictiveness, 2008

Source: Own illustration

In Exhibit 21, the HHI for twelve metals based on the average weighted export concentration is plotted against the average export restrictiveness associated with each metal. The latter is calculated by multiplying the Chinese export tariffs by HS code with the corresponding value of Chinese exports and dividing the result by the total global value of the metal's exports.[284] The result may be interpreted as the average extra charge, a non Chinese importer has to pay when he purchases a basket of intermediate forms of a certain metal on the global market.[285]

As indicated by the grey shaded ellipses, four of the six refractory metals are to the upper right of the non-ferrous base metals. Their position in the chart illustrates that not only are these refractory metals more concentrated, they are also more exposed to Chinese export restrictions. Whereas the average export tariff levied on non-ferrous metals is 0.1 percent, the average extra charge to which molybdenum, manganese, chromium, and vanadium are exposed is 1.6 percent. Niobium, albeit highly concentrated, is only marginally exposed to export restrictions as Brazil, the major supplier, does not levy such taxes. In fact, the average export charge on niobium, 0.02 percent, stems from restricted re-exports of ferro-niobium

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[284] Compare Appendix, Table 45 for Chinese export tariffs by HS code

[285] Assuming that each exporter contributes to the basket according to his share of total exports of the metal and that each intermediate product is contained according to its share of total exports of the metal

from China. The exhibit illustrates that assessing the concentration of supply on a national level through export concentration instead of through production concentration and taking into consideration export restrictiveness yields a new perspective, which better reflects supply security issues to importers. E.g., measured by production, less than 0.9 percent of global chromite ore stemmed from China in 2008. Yet measured by export value, it exported 6.4 percent of all exports of ferro-chromium, the major intermediate form, in which chromium is traded, as well as over 12 percent of chromium articles, including chromium metal. As an export tariff of 20 percent was levied on ferro-chromium in 2008 among other chromium products, this resulted in an average global export charge of 1 percent.

Plotting the average export charge across all intermediate metal forms as an aggregated value allows to compare selected metals. However, it disguises that for certain intermediate products, surcharges were much higher. E.g., China exported over 25 percent of total global exports of ferro-silico-manganese and levied a 20 percent export tariff on the product. This resulted in an average surcharge of 5.1 percent to be borne by non-Chinese importers.

In the case of aluminum, tin, and molybdenum, export tariffs were complemented by export quotas, which were gradually tightened or newly introduced in the case of molybdenum (Exhibit 22):

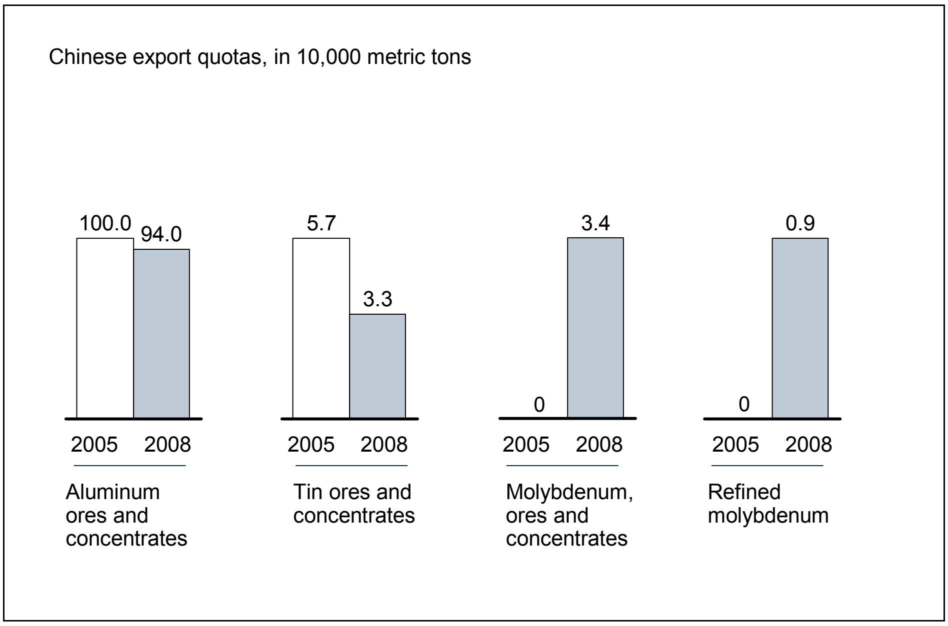

Exhibit 22 – Chinese export quota evolution

Source: Own illustration[286]

This form of export restriction is not captured in Exhibit 21, which implies that the cost effect of all Chinese export restrictions on importers in 2008 and beyond may have been higher than the average export surcharges calculated.

In line with differences in the structure of trade concentration and restrictiveness, the market organization at the interface of suppliers and consumers differs as well for non-ferrous base metals and refractory metals. Distinguishing elements are the absence of a central market place for most refractory metals and the lack of financial instruments to mitigate the risk of price volatility as well as the nature of participants trading actively.

The spot market trade of non-ferrous metals is conducted at centralized stock exchanges such as the London Metal Exchange (LME), whereas refractory metals have until 2010 been traded in a decentralized form only, with prices being set through direct negotiations between producers and consumers or by producers, e.g., in the case of niobium. For non-ferrous base metals, prices are published daily. Prices for refractory metals are published by trade journals based on interviews with trading partners based on a weekly, monthly or longer-term period.

Exchange trading introduces the possibility of forward trading. Two implications of exchange trade emerge. First, this form of trading allows market participants to hedge their exposure to

[286] China Customs 2009

the fluctuation of the commodity's price. Second, the existence of financial instruments in metal trading introduces a new type of investor on a large scale with speculative motives as opposed to industrial market participants. With respect to the first implication, until 2010 industrial market participants only had the opportunity to hedge their exposure to non-ferrous metal prices. As the importance of refractory metals has grown, this has changed. As industrial consumers are beginning to realize the growing importance some of these metals and the cost and revenue risk associated with them, the LME introduced forward trading for molybdenum and cobalt in early 2010.[287]

Scholars are divided on the implications of these different price setting mechanisms and opinions range from the perception that the introduction of exchange trading and thus future trading increases or does not affect volatility. However, several authors concede that exchange trading leads to an increase in market information.[288]

5.1.3 Split of production

Metal supply may stem from three general sources[289]:

- Individual primary supply
  Individual primary supply is usually the most common form of metal supply and relates to metal mined from non-renewable sources as the main product.

- Co- and by-product supply
  This form of supply stems also from non-renewable deposits but the metal is mined as a co-product or a by-product. A co-product status indicates that in order to make the mine profitable the metal must be mined together with the main product and both metals influence output. A by-product status indicates that while the metal is mined together with the main product, its total value is insignificant compared to that of the main product and consequently the by-product's price has no influence on the output[290].

- Secondary supply
  Secondary supply is metal recycled from scrap. Scrap may orginate from home scrap,

[287] LME (2010)

[288] Compare chapter 3.1.3

[289] Tilton (1992), p. 52ff.

[290] The exact differentiation between by- and co product is blurred and not properly defined. Depending on revenue and profit shares, such labeling may also change with changing prices.

generated in the refining phase, new scrap generated during manufacturing or old scrap, resulting from products disposed by consumers.

The supply of a particular metal may stem from all three sources and the nature of factors influencing supply may differ depending on the metal and the source of supply.

The supply of non-ferrous metals stems predominantly from individual primary supply. While most of the time other metals are also extracted when non-ferrous base metals are mined, the latter usually constitute the dominant product. In contrast, three refractory metals are mined predominantly as co- or by-products as illustrated in Exhibit 23:

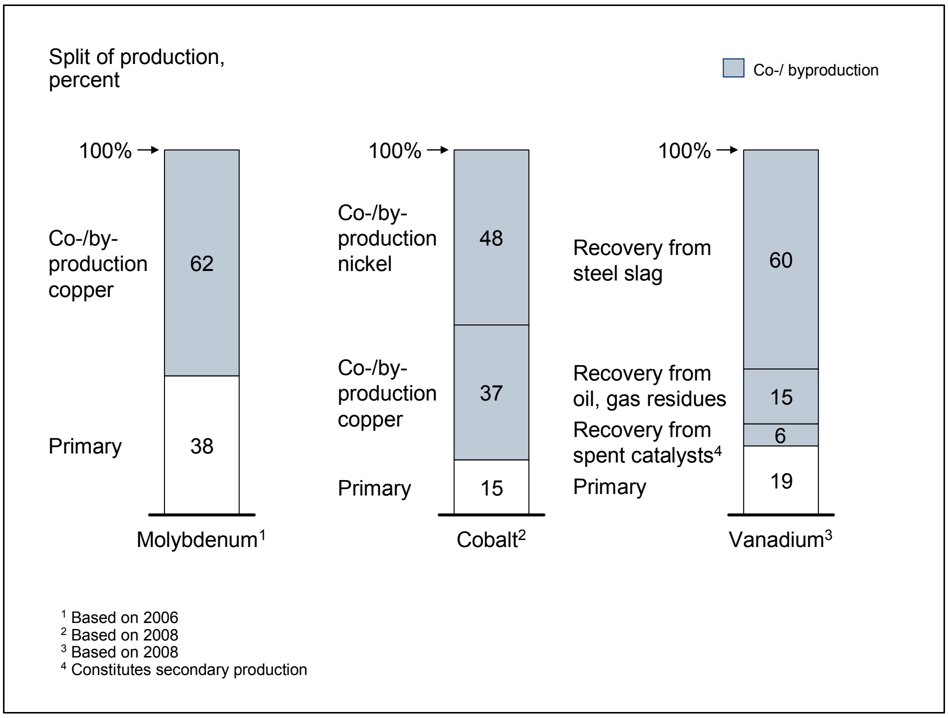

Exhibit 23 – Production split molybdenum, cobalt, vanadium, various years

Source: Own illustration[291]

Over 60 percent of molybdenum was mined as a co-product of copper production in 2006, mainly in Latin America. In 2008 cobalt production stemmed to over 80 percent from co- and by-production of nickel and copper. Vanadium is mostly recovered as a by-product from slags and residues. A minor share is also recycled from catalysts, where the recovery is associated with the recovery of other metals such as cobalt, nickel, and molybdenum[292]. This has important implications. Co- or by-products are mined only when the primary product

291 Molybdenum: Based on data from Raw Materials Group (2007); Cobalt: CDI (2010), p.53; Vanadium: Bunting (2009)

292 Mitchell (1996), p.3

is mined also. Thus, supply of molybdenum, cobalt, and vanadium may not respond to the demand needs of the individual metal but to the supply situation of the main product.[293] Situations of over- or undersupply may therefore appear more pronounced than is the case for metals, which are mined mainly from primary deposits. E.g., in 2001, the molybdenum supply from copper mining remained low despite rising molybdenum prices and an undersupplied molybdenum market as copper producers delayed production "driven by efforts to deal with long-term flat copper prices lasting till 2003"[294]. On the other hand, the price of the refractory metals molybdenum, cobalt, and vanadium is often irrelevant to the viability of a mining project, in which these metals are mined as by- or co-products. This may lead to an oversupply or to a price erosion and to the squeeze-out of primary miners.[295]

From most of their end uses refractory and non-ferrous base metals may be theoretically be recycled as in most applications metals is not dissipated, i.e. irretrievably lost[296]. However, whether or not scrap recycling is a relevant source of supply depends on numerous factors, foremost economic considerations[297]. Most factors influencing the success of secondary supply are metal specific. Due to the large volumes available, old scrap flows of non-ferrous base metals are generally well recycled. Global recycling rates[298] for non-ferrous base metals are illustrated in Exhibit 24:

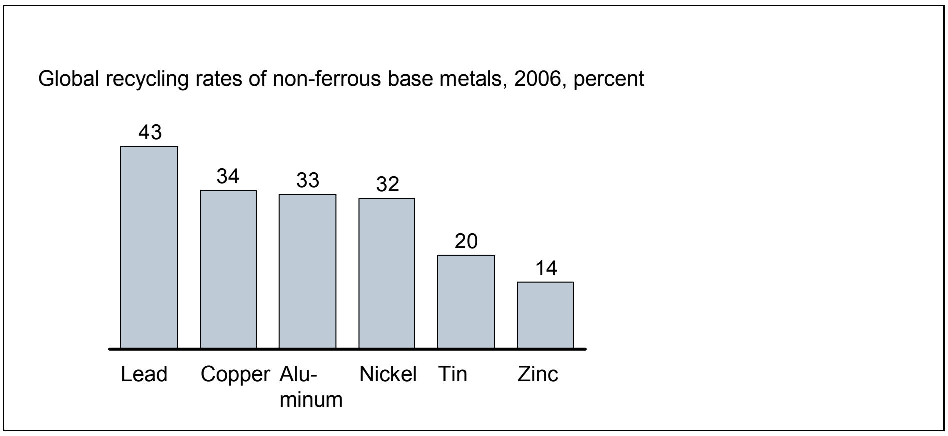

Exhibit 24 – Global recycling rates of non-ferrous base metals, 2006

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[293] Compare Maxwell (1999), p.5, for an example of nickel and cobalt

[294] Langhammer/Zeumer (2010), p.17

[295] Compare chapter 7.2 for an example in the molybdenum market

[296] This is not the case for other minor metals used in electronic components. Compare also Reller (2009), p.134

[297] Henstock (1996), p.6

[298] Recycling rate is calculated dividing global scrap recovery by global consumption.

Source: Own illustration[299]

Global recycling rates of refractory metals are not published and scrap recovery of these metals is thought to be insignificant[300] compared to non-ferrous base metals as these metals are usually contained only in traces in the end product and are thus much more costly to sort and extract.

A comparison of the share of global export value associated with metal scrap relative to total export value of the individual metal reflects the minor role of refractory metal scrap. Exports associated with either non-ferrous base metal comprise close to 5 percent of total exports on average:

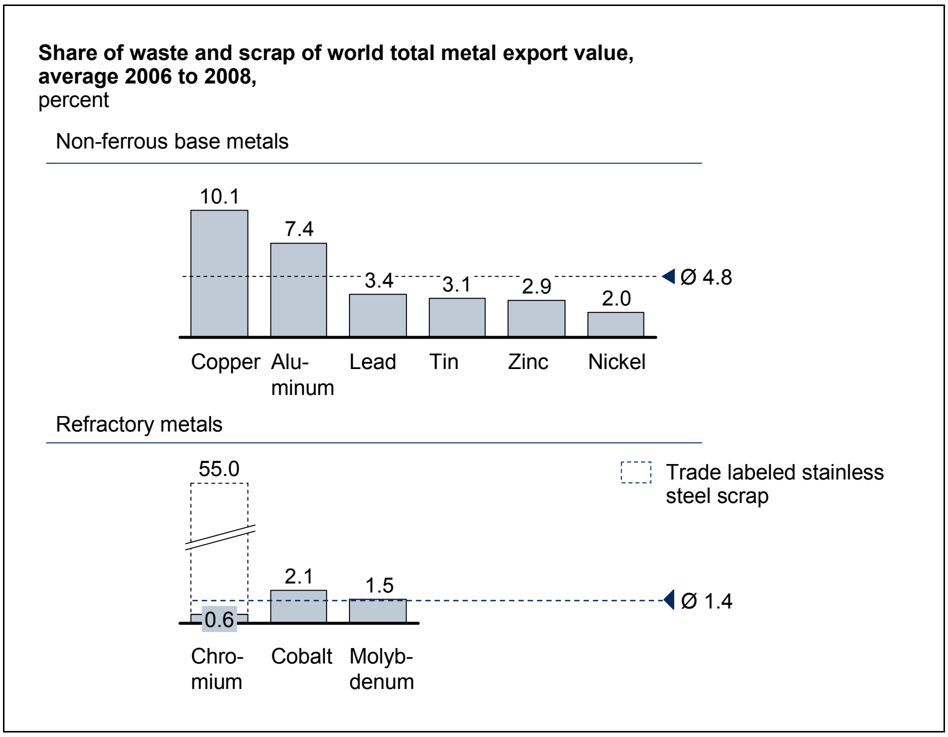

Exhibit 25 – Share of waste and scrap of global metal exports, non-ferrous base metals

Source: Own illustration[301]

For refractory metals, trade of waste and scrap is rarely reported separately on the level of trade data granularity provided by UN Comtrade. Not accounting for stainless steel scrap

[299] Aluminum: Internation Aluminium Institute (2010); Nickel: Reck et al. (2008); Tin: International Research Institute (ITRI) (2010); Copper, zinc, lead: Based on World Bureau of metal statistics (2009)

[300] Henstock (1996), p.222

[301] Compare Appendix, Table 19 for HS codes used

exports, the average export value of chromium, cobalt and molybdenum is 1.4 percent. However, refractory metals are contained in trade of stainless steel and alloyed steel scrap. The value of stainless steel scrap is dominated foremost by the chromium content. Accounting for this form of scrap in the value of chromium trade yields a scrap trade percentage of 55 percent.

The difference illustrates that while metal scrap trade is not reported sufficiently granular, trade flows of alloyed scrap material may contain significant amounts of refractory metals. However, which of these are in the end recovered is unclear.

5.2 Demand side structural differences

In the following chapter, differences between refractory metals and non-ferrous base metals are elaborated with respect to the general structure of demand and demand development. Laying a particular focus on refractory metals, both topics are furthermore analyzed in detail in chapter 6.

Refractory metals have a different demand structure insofar as they are usually used only in very small quantities in the end product. Thus, their share of costs relative to the total cost of the end product is small. Substitution considerations therefore impact refractory metals often only indirectly or only when such considerations are not purely cost based. Despite their small volume, refractory metals provide indispensable functions to steel grades as the dominant intermediate product of refractory metals analyzed in this work as well as to the end product. This contrast, the small volume and cost position and yet the essential functions these metals effectuate in steel[302], makes their role in many applications fundamentally different from non-ferrous metals. While the latter's importance to the end product is beyond doubt, non-ferrous base metals often comprise a more dominant share of material volume in the end product and thus a sizable share of total cost. As such, their influence and their role are much more visible.

The analysis of metal demand development has been subject to numerous studies and concepts. The most widely used methodology by scholars as well as practitioners is the intensity of use (IU) technique.[303] The concept postulates that demand D_{ik} of metal i in an economy k in $t=0$ growing at an annualized rate of r_{ik} till $t=T$ may be expressed as the

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[302] Compare also chapter 6.1

[303] Tilton (1990); compare also chapter 3.2.1

product of economic growth measured as gross domestic product GDP_k and the economy's intensity of use IU_{ik} .

The following formula expresses the relationship:

$$
\begin{aligned}
& D_{ik,t=T} \\
& = D_{ik,t=1}(1+r_{ik})^T \\
& = GDP_{k,t=1}(1+s_k)^T \cdot \frac{D_{ik,t=1}(1+r_{ik})^T}{GDP_{k,t=1}(1+s_k)^T} = GDP_{k,t=1}(1+s_k)^T \cdot IU_{ik,t=0}(1+y_{ik})^T
\end{aligned}
$$

In order to identify similarities or differences in demand development, demand growth and the IU development for non-ferrous metals and the four refractory metals chromium, manganese, molybdenum, and niobium are assessed for the following thirty-four economies listed in Table 18[304]:

Advanced economies		**Emerging and developing economies**	
Western Europe	Austria	Major emerging markets	China[305]
	Belgium[306]		Brazil
	Finland		India
	France		Russia
	Germany	Developing Asia	Indonesia
	Italy		Malaysia
	Netherlands		Thailand
	Norway	Eastern Europe	Czech Republic
	Portugal		Hungary
	Spain		Poland

[304] The thirty –four countries consumed about 90 percent of total non-ferrous metal demand on average. Compare Appendix for details

[305] China comprises China mainland, Hongkong and Macao. Internal trade flows were eliminated.

[306] Belgium comprises Belgium and Luxembourg. Internal trade flows were eliminated.

	Sweden	Other emerging economies	Argentina
	United Kingdom		Chile
Other advanced economies	USA		Mexico
	South Korea		Turkey
	Australia		Ukraine
	Canada		Venezuela
	Japan		South Africa

Table 18 – Economies in the focus of metal demand analysis

Source: Own illustration[307]

Exhibit 26 shows the average demand growth for the six non-ferrous base metals for advanced and emerging and developing economies. Growth rates are calculated based on three-year moving averages from the average between 1994 to 1996 to the average from 2006 to 2008. For simplification purposes and to illustrate the time span covered, the time period is referred to as 1994 to 2008 in the following.

[307] Classification according to World Bank

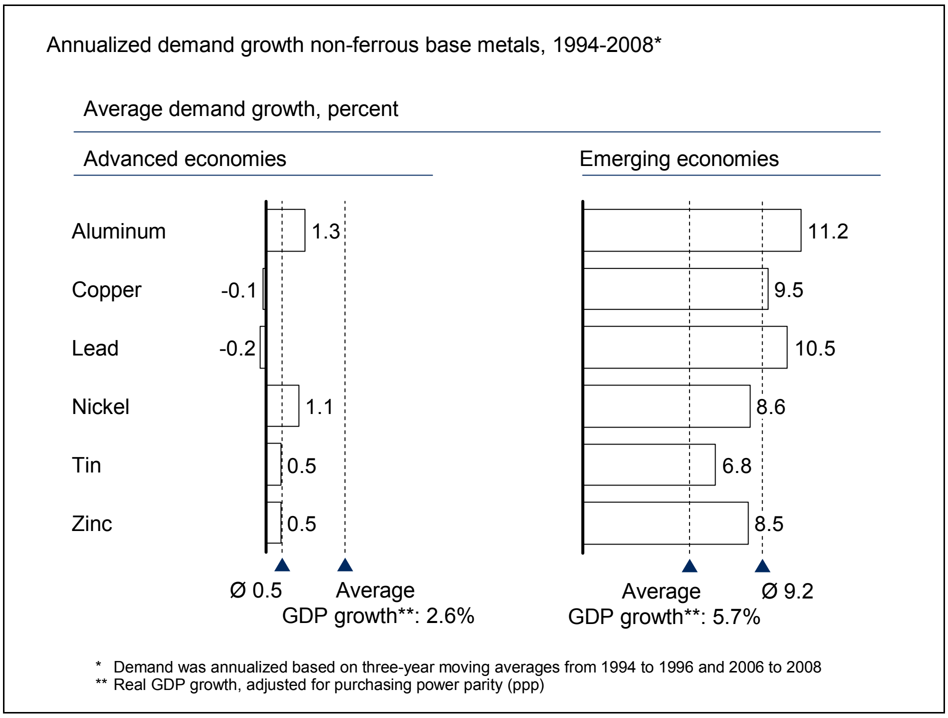

Exhibit 26 – Demand growth of non-ferrous base metals between 1994 and 2008

Source: Own illustration

Overall, demand for non-ferrous metals in advanced economies grew at a modest annualized growth rate of 0.5 percent between 1994 and 2008. For the younger materials aluminum and nickel, demand grew slightly above 1 percent, whereas demand shrank despite the commodity boom for copper and lead, and stagnated around 0.5 percent for tin and zinc. Average real GDP growth adjusted for purchasing power parity in these advanced economies was 2.6 percent on average, above all average metal demand growth rates.

Unsurprisingly, a different picture emerges for metal demand development in emerging and developing countries. Here demand grew at an average of 9.2 percent and ranged from 6.8 percent for tin up to 11.2 percent for aluminum during the same time period. Average annual GDP growth was 5.7 percent for the selected countries, below the demand growth rates of all non-ferrous metals. Complementing this growth analysis with the development of the intensity of use for non-ferrous base metals by regions yields a familiar picture:

Intensity of use development by region, 1994-2008

		Alu-minum	Copper	Lead	Nickel	Tin	Zinc
Advanced economies	United States	–	–	–	–	–	–
	Japan	–	–	–	–	+	–
	WEurope	+/–	–	–	–	–	–
	South Korea	–	–	–	+/–	–	–
Emerging and developing economies	Brazil	+	+	–	+	–	+/–
	Russia	+	+	+	+	+	+
	China	+	+	+	+	+	+
	India	+/–	+	+	–	+	+/-
	Develop. Asia	+	+	–	+	–	–
	EEurope	+	–	+	+	–	–

Note: IU growth < -0.5%: "-"; IU growth > -0.5%, IU growth < 0.5%: "+/-"; IU growth > 0.5%: "+"; n/a: not available

Exhibit 27 – Intensity of use development by region between 1994 and 2008 for non-ferrous metals

Source: Own illustration

The analysis reflects findings from Exhibit 26 that GDP growth in advanced economies outgrew metal demand on average. As a result of this discrepancy, metal intensity of use was generally falling in advanced economies. A notable exception was the development of tin in Japan. IU for nickel in South Korea and aluminum in Western Europe stagnated during the observed time period. In emerging and developing economies, GDP growth was below metal demand growth on average- Dominant trends such as industrialization and urbanization are generally assumed to drive metal demand and result in a rising metal intensity, although region specific differences exist. In China and Russia, intensity of use rose across all metals. In Brazil, IU fell for lead and tin and stagnated for zinc. In India IU stagnated for aluminum and zinc and fell for nickel. In Developing Asian countries, comprising Indonesia, Malaysia and Thailand, IU fell for the mature metals lead, tin and zinc and rose for the younger metals aluminum and nickel as well as copper. In major Eastern European economies, development was similar. IU fell for the mature metals copper, tin and zinc and also rose for the younger metals aluminum and nickel as well as lead.

These region specific distinctions may lie in cultural differences on a microeconomic level also suggested in earlier studies[308]. Nonetheless, it emerges that intensity of use of non-ferrous metals is on average falling in advanced economies while rising in emerging economies and this perception continues to dominate economic analysis of metal demand among practitioners as well as scholars.

However, a different picture emerges when analyzing the demand development of refractory metals. Exhibit 28 illustrates the average growth rates for four refractory metals.

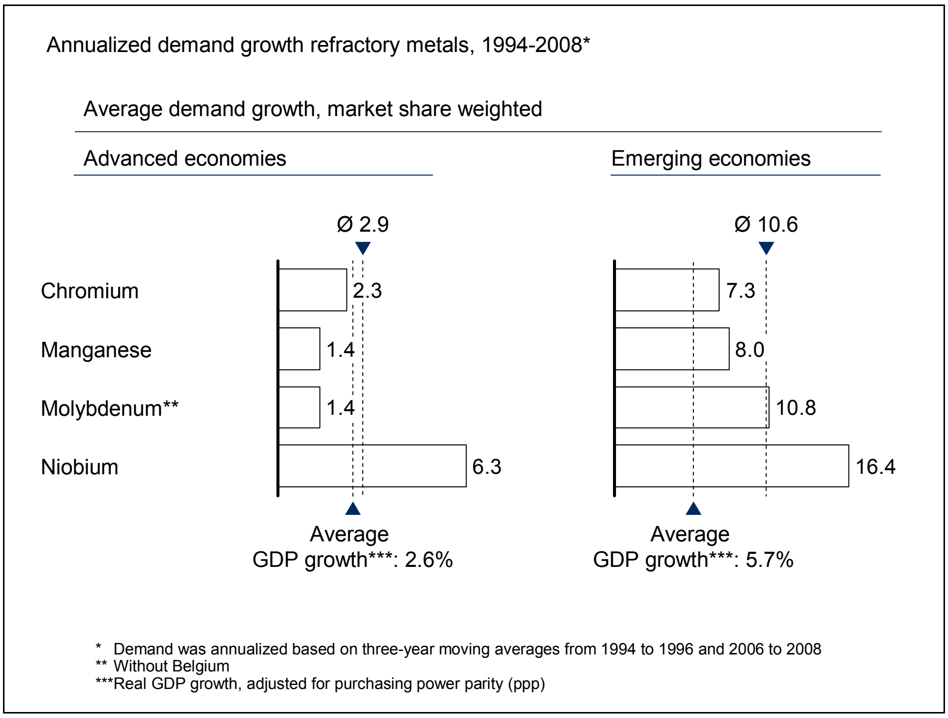

Exhibit 28 – Demand growth of refractory metals between 1994 and 2008

Source: Own illustration

Contrary to non-ferrous base metals, the average refractory metal demand growth rate was slightly above GDP growth in both advanced and emerging economies during the same time period. Even when niobium is excluded, the average demand growth rate in advanced economies was 1.7 percent, more than three times that of non-ferrous base metals between 1994 and 2008. With an annualized demand growth of 6.3 percent of niobium, the metal clearly excelled demand growth of all other metals. In emerging economies, growth rates were 1.5 percentage points higher on average than for non-ferrous metals. Niobium and

[308] Compare Tilton (1990), p.73 for possible explanations for differences in intensity of use in aluminum and lead between the US and the United Kingdom

molybdenum grew strongest, followed by chromium and manganese. Exhibit 29 complements the growth analysis by depicting the intensity of use development:

Intensity of use development by region, 1994-2008

		Chro-mium	Manga-nese	Molyb-denum	Nio-bium
Advanced economies	United States	–	–	–	+
	Japan	+/–	+	+	+
	WEurope	+	–	–	+
	South Korea	+	–	+	+
Emerging and developing economies	Brazil	+	+	+/–	+
	Russia	+	+	+	n/a
	China	+	+	+	+
	India	+	–	–	+
	Develop. Asia	+	–	–	+
	EEurope	–	–	+	+

Note: IU growth < -0.5%: “-“; IU growth > -0.5%, IU growth < 0.5%: “+/-“; IU growth > 0.5%: “+“; n/a: not available

Exhibit 29 - Growth in intensity of use of refractory metals in eight major consuming regions and countries

Source: Own illustration

It emerges that the IU of niobium rose in all markets regardless of stage of economic development. For the other metals, no clear horizontal development picture is identifiable. Molybdenum's IU in advanced economies fell in the US and in Western Europe, yet rose in South Korea and Japan. In emerging economies, molybdenum's record is equally mixed. Rising in Russia and China as well as in Eastern Europe, the metal's consumption per GDP unit fell in India and developing Asia and stagnated in Brazil. Manganese's IU fell in most advanced economies except Japan but also fell in India, Developing Asia and Eastern Europe. Chromium's concentration per unit of GDP fell in the US and stagnated in Japan, yet increased in Western Europe and South Korea and rose in all emerging regions except Eastern Europe.

The IU development suggests that for the refractory metals analyzed above, patterns of development in intensity of use do not appear to flow solely along stages of economic development, at least not during the fourteen year time period analyzed in this work. The distinction to the development in non-ferrous base metals is striking. Specific consumption of refractory metals appears not to decline in general at a certain stage of economic development. Rather, factors reaching across economic performance levels have a dominant influence on the consumption of refractory metals. The unanimously positive development of niobium and the mixed record of other refractory metals suggests that structural differences embedded in the demand profile of these metals together with factors of microeconomic or other nature have a strong influence on the individual metal growth development.

5.3 Summary

In the preceding chapter the supply and demand structure of non-ferrous base and refractory metals were compared. Having demonstrated that refractory metals are underrepresented in literature on the economic development of metal markets despite their growing economic importance, the purpose of the comparison was to find evidence for differences in the structure of both metal groups that justify a separate analysis of refractory metals.

On the supply side, differences exist with respect to the concentration of production, trade and export restrictiveness as well as market organization and source of supply. Production of refractory metals analyzed in this work is generally more concentrated in fewer countries and consequently, export of these metals in its various forms is also more aggregated. It was furthermore shown that China's role as a major supplier in these markets is more pronounced than in non-ferrous base metal markets with the consequence that importers of refractory metals are generally more exposed to Chinese export restrictions and thus face higher average surcharges than Chinese consumers. In this context, it was shown that China's influence is not confined to refractory metals that it produces domestically but generally affects metals, in which the economy has a dominant share in some parts of the value chain. With respect to market organization, refractory metals before 2010 were exclusively traded decentralized as opposed to non-ferrous base metals, which are all traded at central exchanges. This affects both opportunities of market participants to hedge themselves against price volatility as well the exposure of markets to financial investors.

Finally, sources of supply are different between non-ferrous base metals and selected refractory metals. Whereas supply from the former stems predominantly from primary mines, i.e. from mines, which are mined mainly for non-ferrous base metals as well as from secondary production, i.e. recycling, refractory metals' share of recycling is thought to be insignificant. Furthermore, molybdenum, cobalt, and vanadium are to over 60 percent up to 85 percent produced as co- or by-products. As such, their supply depends on the production and demand of the main product, usually nickel, copper or steel and not on the demand situation of the actual refractory metal.

On the demand side, it was demonstrated that the development of refractory metal demand relative to GDP is fundamentally different from patterns found for non-ferrous base metals. While the latter show generally falling patterns in advanced economies and rising patterns in emerging economies, demand for refractory metals relative to GDP does not appear to develop solely according to stages of economic development. Rather, metal specific factors embedded in the demand profile of the individual metal appear to have a pronounced influence.

These structural differences both on the supply and demand side underline the importance to treat refractory metal markets separately from non-ferrous metal markets. Distinctions on the supply side have to be considered when accounting for structural forces influencing the long-term level and volatility of metal prices. An analysis of refractory metal demand has to identify factors, which shape the demand profile of the individual metal and take them into account. Clearly, a projection of refractory metal demand based solely on economic performance will not render realistic results.

6. Demand structure of refractory metals

In the preceding chapter 5.2, a comparison of the demand stucture of non-ferrous base metals and four refractory metals showed that the intensity of use (IU) of the two groups of metals follows different trends. IU of non-ferrous base metals followed largely patterns of economic development. IU in economically advanced countries fell as predicted by economic theory, as GDP growth stems mostly from non-metal intensive sectors such as services. IU in emerging economies was mostly rising, albeit with region specific differences. This is said to be the result of industrialization and of a significant share of GDP growth stemming from metal intensive industries such as manufacturing.[309]

A different picture emerges for refractory metals. Here rise and fall in IU are seemingly disconnected from patterns of economic development, reaching across economically advanced and emerging economies within the same metal market. This suggests that factors other than macroeconomic development play an important role in the development of demand. Furthermore, demand growth of refractory metals in advanced economies measured from the average of 1994 to 1996 to the average of 2006 to 2008 exceeds that of non-ferrous base metals on average.

In the following chapter, an attempt is made to shed light on underlying forces influencing the demand for refractory metals. In chapter 6.1, functions refractory metals effectuate in steel are analyzed and linked to corresponding industry and consumer trends. This qualitative approach is then substantiated by a quantitative analysis of growth in apparent consumption on the basis of the IU technique. In chapter 6.2, the concept of product composition of income (PCI) and material composition of product (MCP), which allow a more granular decomposition of growth of apparent consumption are elaborated. Furthermore, an approach to cluster economies in the focus of this work is suggested to account for the specific demand structure of refractory metals . Subsequently, apparent consumption growth is decomposed for the refractory metals chromium, manganese, molybdenum, and niobium in the chapters 6.3 to 6.6 for the clustered economies. In chapter 6.7, the influence of alloyed steel trade on MCP levels is examined by cluster. Chapter 6.8 complements the preceding analyses with a perspective on refractory metal specific micro trends such as substitution. Chapter 6.9 provides a summary and conclusions.

[309] Compare chapter 3.2.1

6.1 Functions of refractory metals and corresponding long-term trends

Refractory metals are added to steel because they improve the properties of steel either indirectly by influencing processing parameters, e.g., the cooling temperature or by having a direct effect on the properties of the final steel grade, e.g. strength. Such property improvements translate into functions in steel relevant to the manufacturing of steel, e.g. improved machinability, and essential for the end product, e.g. improved corrosion resistance. E.g., adding niobium improves the refinement of the microstructure of steel. This property improves the function of the end product as it allows the development of light-weight steel grades, which despite their lower weight have a higher strength than ordinary steel grades. Such steel grades allow the end application, e.g. an automobile, to function with less material at more demanding operating parameters.

As growth in apparent consumption of refractory metals is essentially influenced by demand for certain end applications, it is the induced improvement of end use functions that drives the demand for refractory metals[310]. The following exhibit lists the major end use functionalities by alloy[311]. Vanadium as an important steel alloy is included.

[310] Improved handling, such as weldability and machinability also play a role in the choice of alloys.

[311] Following Stahlfibel (1990), p.10f. Listed are those properties, in which any of the five metals are classified as "stark verstärkend" - strongly increasing

Properties of alloying elements in steel

	Chromium	Manganese	Molybdenum	Niobium	Vanadium
Corrosion resistence	++	+	++	+	+
Strength	+	+	++	++	++
High temperature strength	++	+	++	+	+
Wear resistence	+	++	+	+	+
Oxide & sulfur fixing		++			

+ increasing ++ strongly increasing

Exhibit 30 – Functional profile of refractory metals in steel

Source: Own illustration

The dominant functions that either refractory metal effectuates in steel are corrosion resistance, strength, and high temperature strength as well as wear resistance and oxide and sulfur fixing in the case of manganese. Differences in the functional profile suggest distinct functional demand, i.e. demand growth characteristics.

Different long-term trends affect the demand for refractory metals through the functions they bring to bear in steel and stainless steel. The three major application categories for high strength low alloy steel (HSLA) are pipe line, automotive and structural[312] and industrial applications, transportation and building and construction for stainless steel[313]. A relentless performance increase within these categories leads to an ever increasing advancement of the operating parameters temperature, pressure and velocity. At the same time, a trend is visible towards ever lighter materials, which nonetheless can withstand more challenging operating parameters to address carbon emissions and other environmental concerns.[314]

312 Heisterkamp/ Carneiro (2001), p.1

313 Nickel Institute (2007)

314 Drewes/ Walker (2001), p.1ff.

While these trends are not new, a rising awareness for the issue of climate change, an increased necessity for sustainable industry solutions and for a sustainable expansion of the use of steel as demand in emerging economies surges[315], all accelerate the development of more advanced steel grades and mediate a shift towards high performance steel grades.

In addition, urbanization and industrial production are taking place in regions, which are located in more corrosive environments and face increasingly corrosive media, like sour gas and higher sulfur content in oil[316]. Water purification and desalination to answer rising demand for clean potable water in light of increasing pressure on available water supplies are further trends, which increase the demand for steel grades able to handle such corrosive environments.

Parallel to these industry trends, the establishment of a state of the art industrial infrastructure and ongoing urbanization accompanies economic growth in emerging economies led by China.[317] Furthermore, rising consumer spending[318] in emerging markets and access to products of western quality standards breed an increasingly sophisticated and powerful consumer class demanding similar standards and quality improvements from domestic brands. Exhibit 31 summarizes how these developments accelerate industry and consumer trends:

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315 Korchynsky (2005), p.1f

316 Heisterkamp/ Carneiro (2001), p.7; Langhammer/ Zeumer (2010), p.16

317 Boyer/ François (2009), p.21

318 Consumer spending in emerging markets is reported to have surpassed US consumer spending since 2007 and comprised over 30 percent of total global consumer spending in 2008. The Economist (2010), p.9

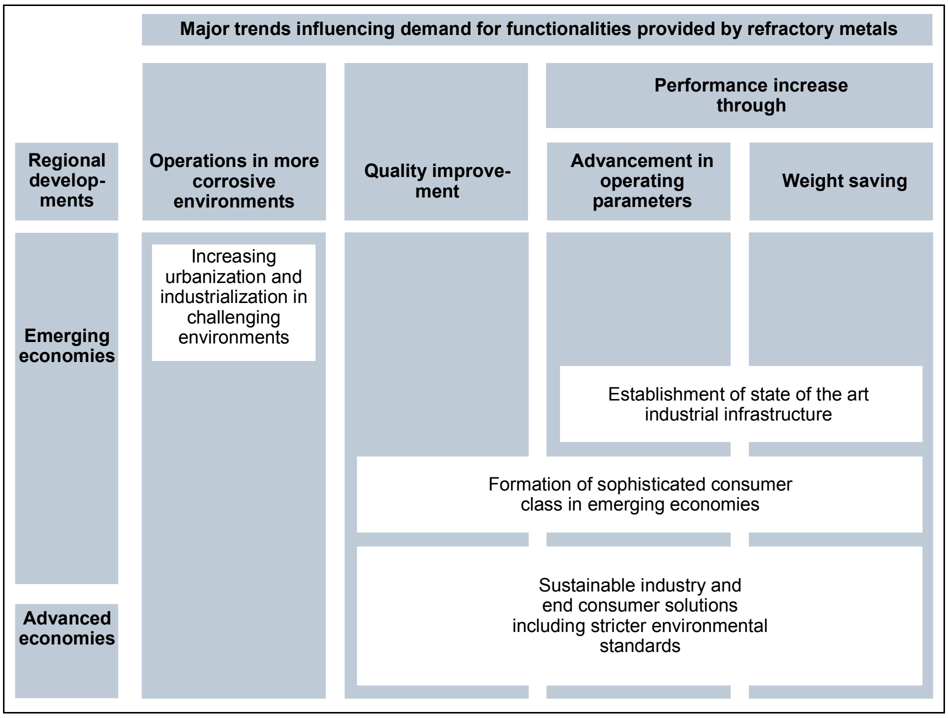

Exhibit 31 – Long-term trends and regional developments

Source: Own illustration

An example for operations in more corrosive environments are constructions in places like the Gulf region, which through its proximity to the coast and the desert are particularly challenging for steel materials. Also, due to environmental pollution in certain strong growth locations in emerging economies, requirements for the corrosion resistance of structural elements are particularly high[319].

The trend quality improvement refers to enhancing the property of an existing application, usually durability, without changing operating parameters, e.g., the replacement of galvanized steel for chromium containing stainless steel in automotive exhaust pipes. Performance increases refer to industrial operations and consumer products, the latter occurring with a relevant impact for refractory metals mainly in the automotive industry.

Exhibit 32 illustrates how industry and consumer trends affect the demand for refractory metals through the functions they bring to bear in steel:

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319 SCI (2010), p.1

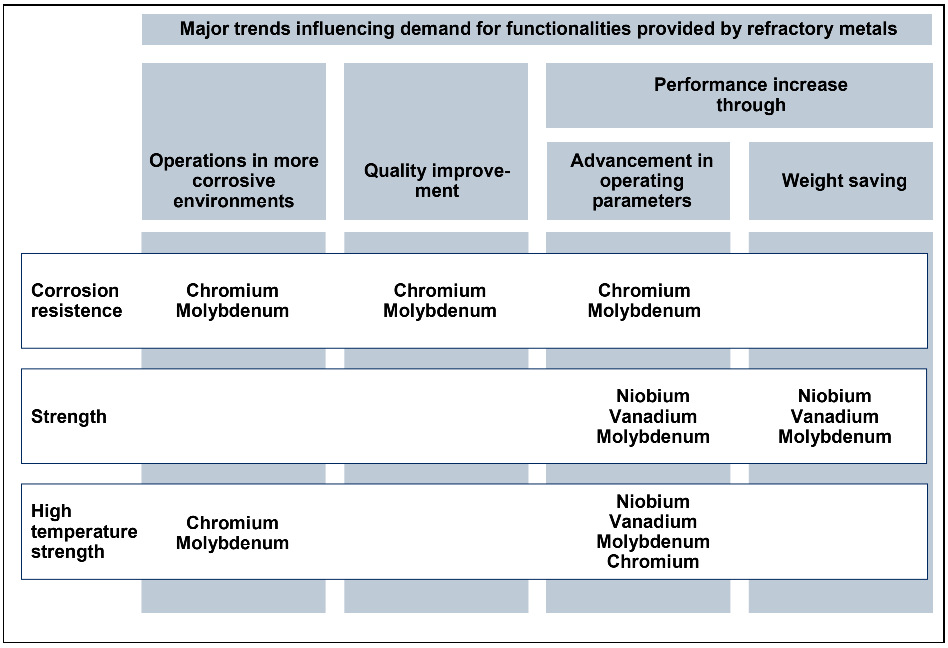

Exhibit 32 – Long-term industry trends affecting the demand of refractory metals through their functional profile

Source: Own illustration

Chromium and to a lesser extent molybdenum in combination with chromium in stainless steel are the main benefactors of a trend towards an exposure of steel grades to increasingly corrosive environments and higher corrosion due to advancing operating parameters such as higher pressures and temperatures. In this context, increasing efficiency by burning fuel at higher temperature also requires steel grades able to provide elevated temperatures strength, a further functionality provided by both metals. Furthermore, relentless quality improvements of existing applications further benefits both alloys.[320]. The aspiration for ever lighter yet higher-strength steel grades is benefiting the demand for niobium, vanadium and molybdenum in HSLA steel grades.

Functional demand for refractory metals originates in the above deduced industry and consumer trends and greatly influences the individual demand for refractory metals. Consequently, the nature and characteristics of demand growth of the individual metal should reflect this. In the following chapter, growth in apparent consumption is therefore

[320] Niobium is also reported to have been studied as an effective alloying element in ferritic and martensitic stainless steel to improve both corrosion resistance and high temperature strength. Given that only a minor share of niobium is used in stainless steel, the metal is not considered a major benefactor of trends towards more corrosive environments. Compare Hiramatsu (2001), p.2

decomposed into respective drivers to further substantiate the function related growth of refractory metals.

6.2 Methodology of demand growth decomposition

In chapter 5.2, demand D_{ik} for a metal i in an economy k was expressed as the product of GDP_k and the intensity of use IU_{ik}. According to the intensity of use technique[321], IU_{ik} may be expressed as the product of

- the production composition of income PCI_k, i.e. the economy's output of the product, in which the refractory metal is used relative to the economy's GDP
- the material composition of product MCP_{ik}, measuring the demand of the metal relative to the output of product in which it is contained

The following formula illustrates the relationship:

$$
\begin{aligned}
&D_{ik,t=T} \\
&= D_{ik,t=1}(1+r_{ik})^T \\
&= GDP_{k,t=1}(1+s_k)^T \cdot \frac{D_{ik,t=1}(1+r_{ik})^T}{GDP_{k,t=1}(1+s_k)^T} \\
&= GDP_{k,t=1}(1+s_k)^T \cdot \frac{P_{k,t=1}(1+u_k)^T}{GDP_{k,t=1}(1+s_k)^T} \cdot \frac{D_{ik,t=1}(1+r_{ik})^T}{P_{k,t=1}(1+u_k)^T} \\
&= GDP_{k,t=1}(1+s_k)^T \cdot PCI_{k,t=1}(1+w_k)^T \cdot MCP_{ik,t=1}(1+x_{ik})^T
\end{aligned}
$$

While all variables are time dependent, GDP_k and PCI_k are only dependent on the economy k, whereas MCP_{ik} is also dependent on metal i.

The growth rate r_{ik} of metal demand may therefore be expressed as the product of the growth rates of GDP, PCI and MCP and can be decomposed accordingly:

$$r_{ik} = (1+s_k)\cdot(1+w_k)\cdot(1+x_{ik})-1$$

As illustrated in chapter 4.3, Exhibit 15, the four refractory metals in focus are used as alloying elements in steel. The variables PCI_k and MCP_{ik} are therefore calculated based on

[321] Compare chapter 3.2.1

the steel production of the individual economies. In this context it is important to differentiate between steel production and steel consumption. The apparent consumption of refractory metals was calculated based on imports, exports and domestic production of the metals in their intermediate forms. In these forms, they are used in the domestic production of alloyed steel. Therefore, production is used as the divisor.[322]

MCP is the only metal dependent variable, measuring a refractory's metal concentration in steel. The variable should reflect the functional demand for refractory metals inferred in the preceding chapter 6.1 and is therefore in the focus of the subsequent analysis. GDP and PCI are metal independent variables and are influenced by a wealth of factors depending on the individual economy. Further analysis of GDP and PCI beyond the variables' share of apparent consumption growth is therefore out of the scope of this work.[323]

As a further step to better comprehend underlying drivers of refractory metal demand, developing a hypothesis how to cluster countries of similar IU development and level is essential. A key finding of chapter 5.2 was that economic performance alone is unable to explain differences in demand development between economies. Clustering economies by their GDP per capita level to explain the development of IU as suggested in numerous studies on non-ferrous metals is therefore insufficient to describe the demand development of refractory metals. Clustering by geography seems equally inadequate. Given that the main usage of refractory metals is in steel production, it is highly probable that the level of domestic steel production has a pronounced influence on apparent consumption of refractory metals and the development. Therefore, the traditional GDP per capita cluster is expanded by the level of steel production in a particular country and MCP, i.e. the apparent consumption of a metal per steel production rather than IU, the apparent consumption by GDP is tracked. Exhibit 33 illustrates the country clusters resulting from this approach[324]:

[322] See chapter 6.7 for a consideration of alloyed steel trade

[323] Compare chapter 8.2.2 for further discussion

[324] Absolute figures for steel production are used as plotting steel production relative to GDP would not have influenced significantly the attribution of economies to clusters and would not have altered China's dominance in cluster 1.

Steel production, kt	<15,000	<25,000; >15,000	>25,000
>50,000	1 China, India, Russia		7 USA, Japan, South Korea*
<50,000 >10,000	2 Brazil, Turkey, Mexico, Poland*, Ukraine		6 Germany, United Kingdom, Italy, Spain, Belgium, Canada, France
<10,000	3 Thailand, Indonesia, Malaysia, Venezuela, Chile, South Africa	4 Portugal, Argentina, Hungary, Czech Republic	5 Australia, Sweden, Norway, Netherlands, Finland, Austria

GDP, USD per capita, real, ppp-based

* South Korea's real GDP per capita, ppp adjusted was 21,000 USD/ capita in 2008, Poland's real GDP per capita was 16,000 USD/capita in 2008

Exhibit 33 – Country cluster

Source: Own illustration

Assigning the economies in the focus of this work according to the suggested clustering method yields seven groups of countries. Exhibit 34 depicts the total steel production and the average GDP per capita by cluster:

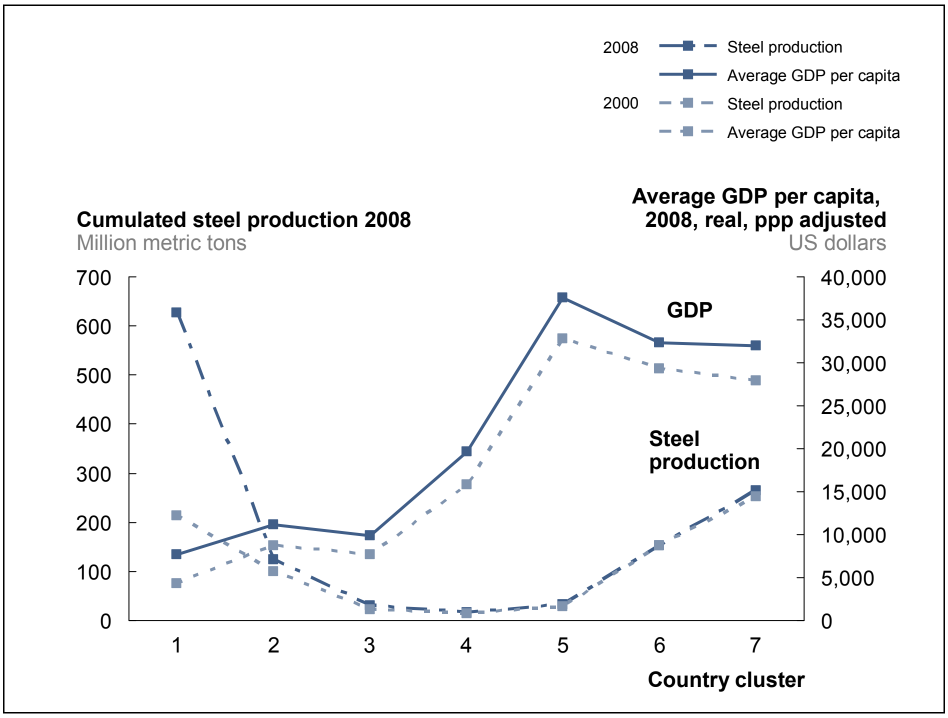

Exhibit 34 – Steel production and average GDP per capita by cluster, 2000 and 2008

Source: Own illustration

Economies in cluster 1 combined both the highest cumulated steel production and the lowest average GDP per capita. With over 500 million metric tons in 2008, China produced the major share. All advanced economies except Portugal are in clusters 5 to 7. The grey dotted lines depict steel production and GDP per capita in 2000. The line for GDP has shifted almost parallel. In all clusters GDP per capita increased by between 2,000 and 4,000 US dollars per capita from 2000 to 2008. Given that emerging economies started from a low level of GDP in 2000, this translates into higher GDP growth rates than in advanced economies. Cumulated steel production experienced a tremendous increase in cluster 1 by a factor of 3 but remained relatively stable for all other clusters.

Overall, the development of steel production and GDP per capita between 2000 and 2008 should be reflected in apparent consumption growth. Especially the strong increase in steel production in cluster 1 is expected to be a major lever for growing consumption of refractory metals. At the same time, a growing concentration of refractory metals in steel production in cluster 1 despite such strong steel growth would be a strong indicator that the increasingly relevant functions refractory metals effectuate in steel are not limited to advanced economies. Specifically, the gap in GDP per capita between clusters 1, 2, and 3 and clusters 5, 6, and 7 should be reflected in MCP levels of refractory metals, whose use is indeed dependent on an economy's stage of economic development.

In the following chapters 6.3 to 6.6, apparent consumption is used to approximate metal demand and decomposed into respective shares attributable to GDP, PCI, and MCP on a regional basis, following the clustering hypothesis displayed in Exhibit 33. The time periods before and during the crisis are depicted separately. As apparent consumption is calculated without stock changes due to lack of data, figures are presumably more volatile as the dampening element of stock in and outflows is missing. To account for this higher volatility, growth is calculated based on three year rolling averages. Specifically, the growth of apparent consumption for the period before the boom is calculated from the average of 1994 to 1996 to the average of 2000 to 2002 and during the boom from the average of 2000 to 2002 to the average of 2006 to 2008. For simplification, the first period is expressed going forward as 1994 to 2001, the second period as 2001 to 2008 to illustrate the maximum span of years covered.

6.3 Chromium

Chromium is crucial for the production of stainless steel, its major application, as it is the ingredient that makes steel stainless. A minimum of 10.5 percent of chromium is added to steel to receive a highly improved corrosion resistance compared to ordinary carbon steel. This resistance is due to an invisible chromium-rich film, which accumulates at the surface of stainless steel. It is inert, adherent to the metal and resistant to a wide range of corrosive media. Another main advantage is that it is self-repairing through the reaction with oxygen, thus damage by abrasion and other mechanical actions is instantaneously repaired.[325] Corrosion resistance and other properties may be improved through the addition of other alloying elements but through its unique role in stainless steel, chromium is irreplaceable and is considered to have no substitute.[326] Chromium's other use is as a alloying element in specialty alloys as well as a chemical. Given this unique role and the critical importance of stainless steel in modern society and in military applications, chromium is therefore considered one of the most important strategic and critical materials.

In the following chapter, the underlying drivers of intensity of use (IU) growth, the material composition of product (MCP), i.e. chromium intensity in domestic steel production and the product composition of income (PCI), i.e. the growth of steel production relative to GDP will be analyzed on a regional basis. Chapter 6.3.2 summarizes the findings of the chapter.

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[325] Stainless Steel Advisory Service (SSAS) (2001), p.1f.

[326] USGS (2010a), p.3

6.3.1 MCP and PCI analysis of chromium demand growth

Chromium apparent consumption has enjoyed strong growth on the back of an increasing demand for stainless steel during the time period observed. Apparent consumption by cluster is displayed in Exhibit 35:

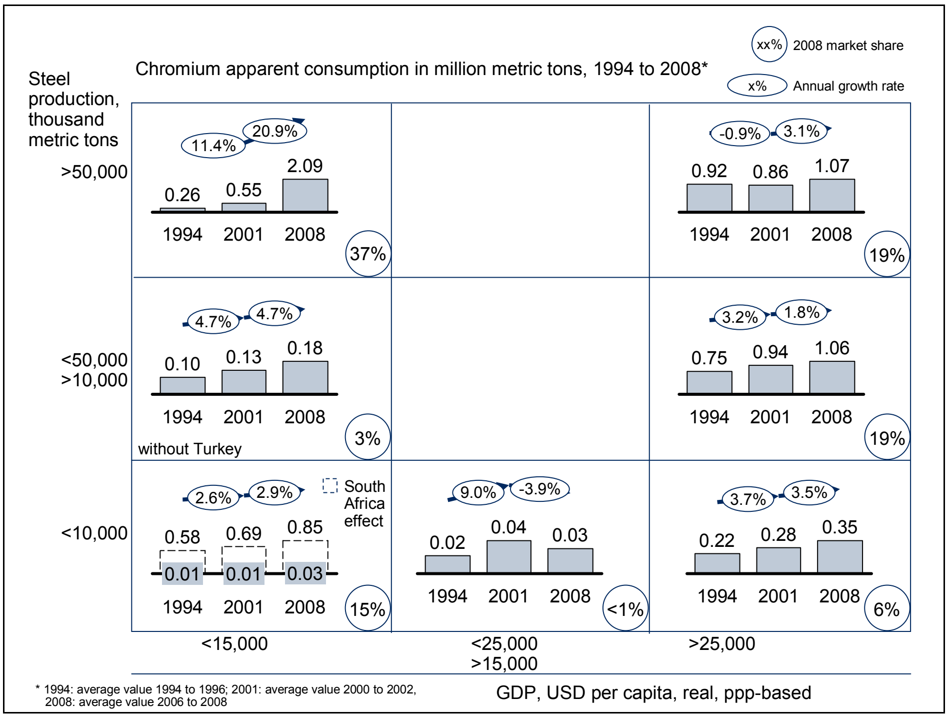

Exhibit 35 – Chromium apparent consumption growth by cluster, 1994 to 2008

Source: Own illustration

Chromium apparent consumption enjoyed strong annualized growth in emerging economies throughout the observed time period whereas growth rates in advanced economies were fluctuating.

In cluster 1 including China, India and Russia, where over 37 percent of global apparent consumption were consumed in 2008, annual growth rated during the boom almost doubled compared to the pre-boom period. In the other major consuming clusters 6 and 7, growth was less steady. In cluster 7, combining Japan, the US and South Korea, apparent consumption fell prior to the boom on average and just recovered till 2008. In cluster 6 comprising major European steel producing economies, growth leveled off during the boom. Only in cluster 5 growth remained steadily above 3 percent from 1994 throughout 2008. Overall emerging economies consumed over 50 percent of global demand, although figures for South Africa indicated in the lower left cluster 3 are subject to qualification. South Africa is a major producer of chromite ore and chromium products yet does not have a large domestic market. It is therefore assumed that a calculated apparent consumption of 820 thousand metric tons on average between 2006 and 2008 is widely overestimated. Presumably, chromium is exported in a form not captured in the calculation of apparent consumption.

The following exhibit illustrates the decomposition of growth into the respective drivers:

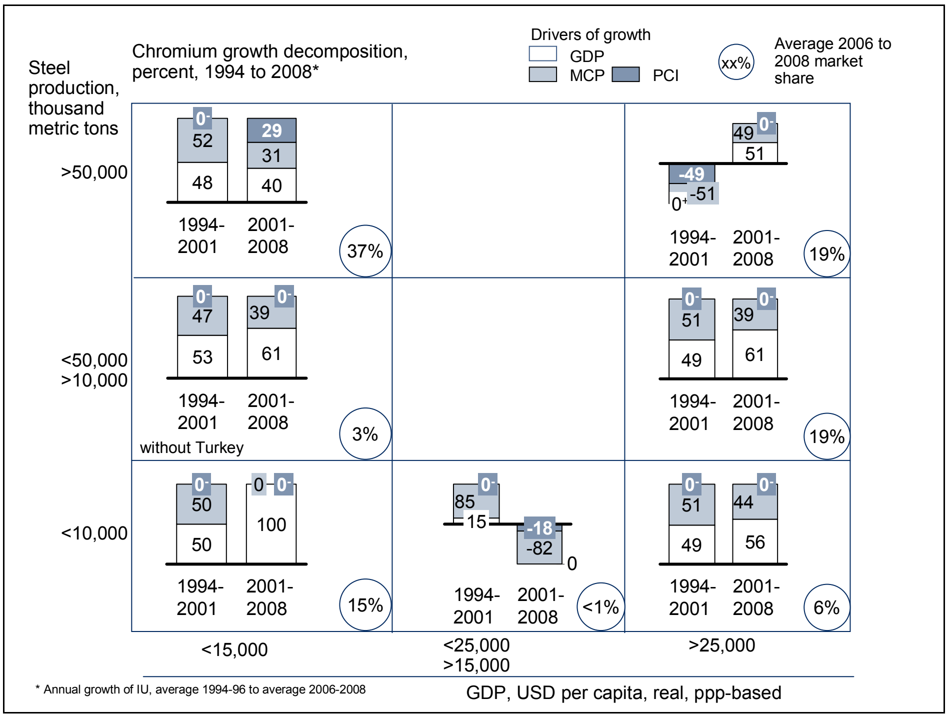

Exhibit 36 – Decomposition of chromium growth by cluster, 1994 to 2008

Source: Own illustration

For advanced economies, growth before and during the boom was split between an increasing intensity in steel as well as growth in line with GDP. In all clusters in the right column comprising advanced economies, PCI, i.e. steel production per unit of GDP fell throughout the observed time period. Since chromium growth rates were still positive with the exception of cluster 7 prior to the boom, an increasing intensity overcompensated for falling steel production, indicating an ongoing specialization towards stainless steel. In cluster 1, strong steel growth relative to GDP during the boom accounted for a third of demand growth. Nonetheless, despite strong steel growth, increasing concentration of chromium in steel attributed another 30 percent to total growth, suggesting that stainless steel production is outgrowing carbon steel production. The residual was growth in line with GDP. Overall, an increasing concentration of chromium in steel production accounted for 40 to 50 percent of apparent consumption growth in all major clusters except cluster 3.

As the MCP variable is the only metal dependent variable and therefore best suited to reflect the influence of functional demand affecting chromium, MCP rates by cluster and period are depicted in Exhibit 37:

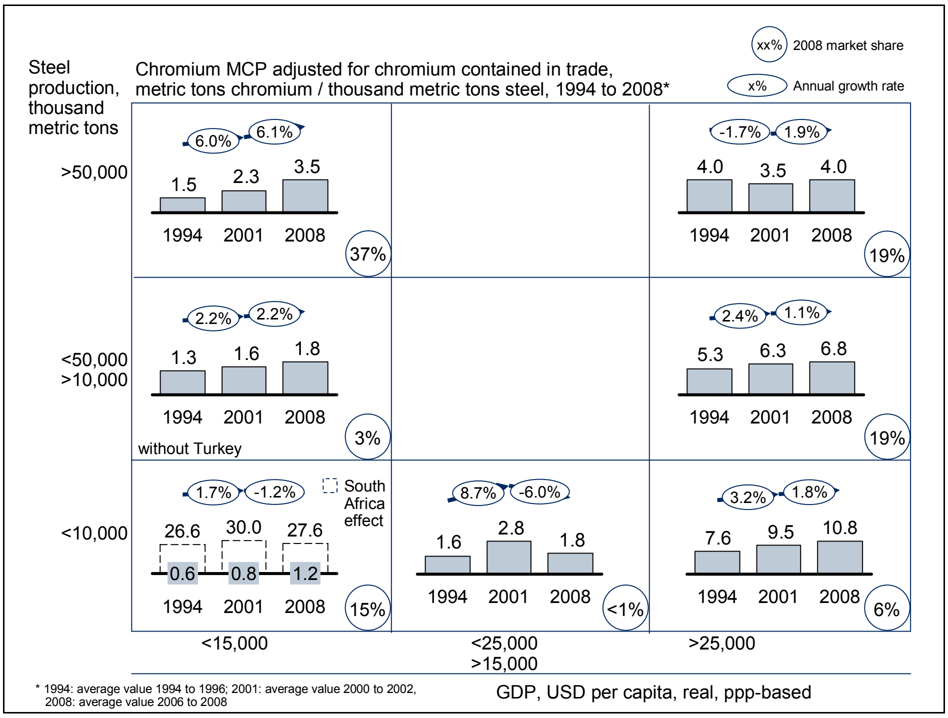

Exhibit 37 – MCP rates chromium by country cluster, 1994 to 2008

Source: Own illustration

The exhibit reflects an overall increase in the intensity of chromium per ton of produced steel in emerging economies. In cluster 1, MCP grew at constant rate of 6 percent annually between 1994 and 2008. In cluster 2, annual growth was lower but equally steady at just over 2 percent. In advanced economies, the increase of chromium concentration in steel production grew slower or stagnated. In cluster 5 and 6, growth in MCP slowed during the boom, presumably because the fall in steel production per GDP slowed. In cluster 7 comprising the US, Japan and South Korea, MCP rates remained at 4 metric tons per thousand tons of produced steel on average during the observed time period with minor fluctuations.

It stands out that the average MCP rate in the major consuming cluster 1, including China, India and Russia has already reached levels of the cluster 7 economies US, Japan and South Korea, despite a large gap in economic development approximated by per capita income levels. Also, while growth in chromium intensity per unit of steel production has stagnated in the latter, undeterred growth in cluster 1 suggests that it will soon surpass levels of this cluster. Emerging economies in cluster 2 remained below cluster 1 by a factor of two. MCP levels in cluster 3 were even lower when adjusted for an inflated value in South Africa. Overall, chromium intensity in emerging economies appears to fall with falling steel production, which suggests that some of these economies are net importer of stainless steel.

Major European producing economies, cumulated in cluster 6, led by Belgium, Germany, Italy, and Spain maintained a higher average concentration of 6.8 tons chromium per one thousand metric tons of steel produced. Finally, the highest average MCP levels are found in cluster 5. Here, Finland is the main consumer of chromium with an average MCP rate between 2006 and 2008 of 27 tons of chromium per one thousand metric tons of produced steel. Other major consumers are Sweden and the Netherlands with MCP levels of 12 and 15.0 respectively, followed by Austria and Australia with 4.6 and 2.7. Norway does not consume significant amounts of chromium. The high MCP rates of the Scandinavian countries may be explained by the presence of highly specialized stainless steel and other alloy producers such as Outokumpo and Sandvik, whose main production centers are in Finland and Sweden, respectively.

It is noteworthy that large differences between economies in the major consuming clusters 1 and 7 exist as illustrated in the following exhibit:

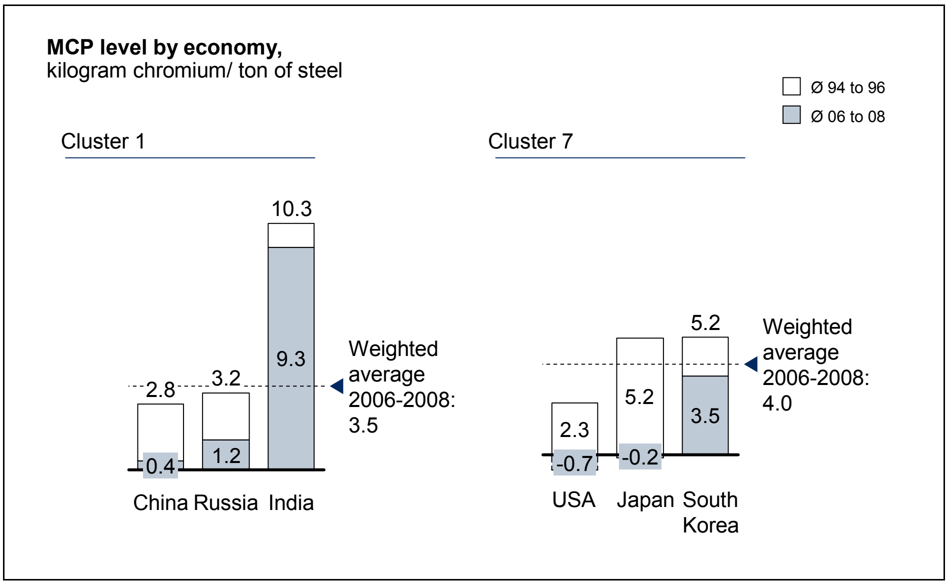

Exhibit 38 – Chromium MCP level of economies in cluster 1 and 7, 1994 to 2008

Source: Own illustration

MCP levels of China and Russia have surpassed the US level during the observed time period from the average of 1994 to 1996 to the average of 2006 to 2008 but both remain below that of South Korea and Japan by a factor of around 2. Chromium concentration only grew in South Korea and fell slightly in the US and Japan during the observed time period. India's high rate may in part be explained by the country's position as a major global supplier of chromium and by the popularity of a stainless steel grade family named the 200 series, which is widely used for cook ware and uses manganese, available from domestic sources instead of nickel, which has to be imported[327].

However, so far MCP levels have been compared without adjusting for chromium contained in stainless steel trade. This may lead to an over- or underestimation of chromium actual domestic consumption. As stainless steel trade is reportedly separately from carbon steel trade and contains a minimum of 10.5 percent of chromium[328], an estimation of chromium content contained in exports and imports is possible. Thus, a more accurate calculation of apparent consumption of chromium is possible. In order to remain consistent, the divisor, domestic steel production, also needs to be adjusted for exports and imports to calculate apparent consumption of steel and to receive the intensity of chromium in steel used for domestic consumption $MCP_{ik}^{Domestic}$:

$$MCP_{ik}^{Domestic} = \frac{D_{ik} + c(I_k) - c(E_k)}{P_k + I_{ip} - E_{ip}}$$

$c(I_k)$ denotes the chromium content in imports of stainless steel, $c(E_k)$ the chromium content in exports of stainless steel, I_{ip} and E_{ip} the imports and exports of steel.

Exhibit 39 displays the adjusted MCP rates by cluster:

327 Australian Stainless Steel Development Association (2006), p.2. Compare also chapter 6.8.2 for further details

328 SSAS (2001), p.1ff. The standard grade of the still dominant 300 series grade family contains 18 percent chromium. The second largest grade family, the 400 series, contains between 13 percent and 17 percent chromium. An average of 15% chromium is assumed to be contained in traded stainless steel. Compare also chapter 6.8.2

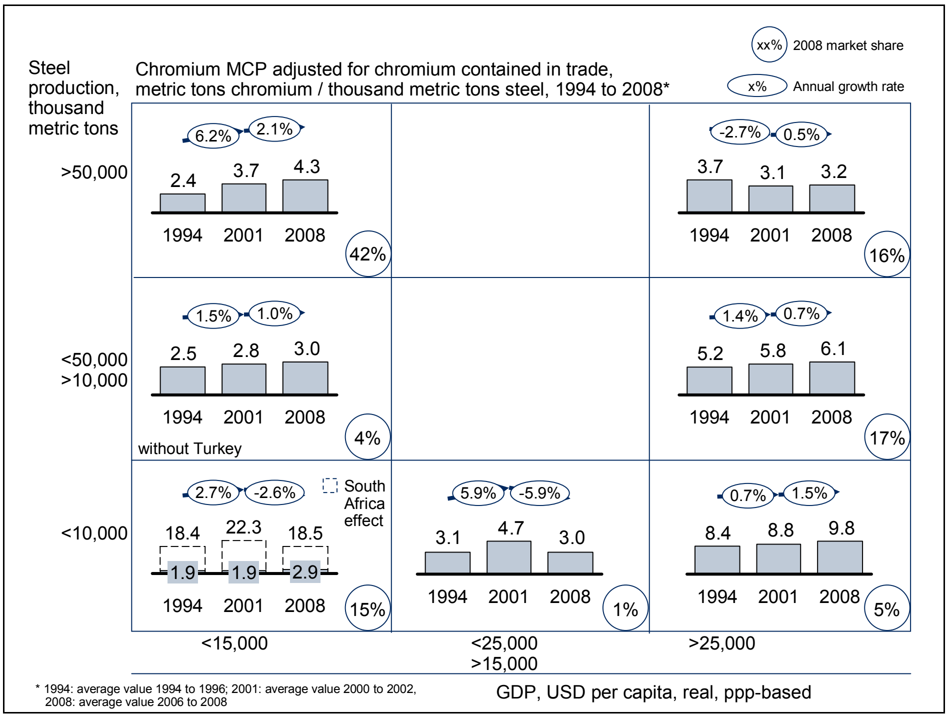

Exhibit 39– MCP development of domestically consumed chromium by country cluster, 1994 to 2008

Source: Own illustration

The MCP levels in the above exhibit depict a more accurate picture of the level of chromium intensity of steel used domestically. An important finding is that the country cluster 1 including China, India and Russia, which has been the main driver for chromium demand growth in the analyzed period surpassed MCP levels of advanced economies with comparable steel output already before the crisis. Bolstered by net stainless steel imports, the MCP level of cluster 1 already reached an average MCP level of 3.7 metric tons chromium per thousand tons of domestically consumed steel for the time period between 2000 and 2002 compared to an average of 3.1 in the US, South Korea and Japan. In 2008, concentration of domestically consumed stainless steel in cluster 1 was already more than 30 percent above the average in cluster 7. Adjusted for stainless steel trade, MCP growth rates in cluster 1 slowed considerably during the boom. Having grown at 6 percent annually from 1994 to 2008 as depicted in Exhibit 37, growth of chromium intensity of domestically consumed steel was only 2 percent during the boom. This suggests that chromium intensity of domestically consumed steel may not advance significantly beyond the 2006 to 2008 average rate of 4.3 but rather that imports may be replaced by domestic production.

Concentration of chromium in steel in cluster 2 is considerably higher when adjusted for stainless steel trade, which confirms the hypothesis that the countries cumulated in this cluster are net importers of stainless steel on average. With an average of 3 metric tons of chromium for one thousand metric tons of steel produced between 2006 and 2008 the MCP level is similar to that found in cluster 3 adjusted for South Africa but still below cluster 1.

MCP levels in advanced economies adjusted for stainless steel trade are all lower than the unadjusted level, which suggests that on average these economies are net exporters of stainless steel. Nonetheless, the differences between the clusters 5, 6, and 7 persist. Concentration for cluster 6 and cluster 5 remain above cluster 7 by a factor of 2 and 3, respectively on average between 2006 and 2008. This indicates that reasons beyond economic development, e.g., cultural reasons may also play a role in explaining the use of stainless steel. E.g., an unpublished document by the Nickel Institute suggests that in the USA the popular aluminum is an accepted alternative to stainless steel[329], which may in part explain the low chromium concentration in this country.

Overall, the concentration of chromium consumed domestically appears to have stabilized on average in cluster 5, 6, and 7 and growth slowed considerably in cluster 1. This suggests that concentration may approximate a level of saturation in advanced economies and advances at a slower pace in emerging economies.

6.3.2 Summary

The purpose of the preceding chapter was to develop a more granular yet quantitative understanding of forces influencing the intensity of use (IU) development of chromium as a major driver of chromium demand growth next to growth in line with GDP. In this context, the share and development of GDP, the material composition of product (MCP) and product composition of income (PCI) were analyzed. Findings are summarized as follows:

- Driver of growth in chromium apparent consumption
  The major driver of growing chromium IU appears to be a rising MCP level, i.e. a rising intensity of chromium in steel. This holds true regardless of the stage of economic development and can be witnessed in emerging economies as well as for developed economies' steel production and consumption. In advanced economies this rising concentration compensates for a falling growth of steel production relative to GDP. Only in cluster 1 has steel production still grown above GDP. Here, PCI attributes roughly 30 percent to total growth in apparent consumption.

[329] Nickel Institute (2007), p.20

- Level of MCP rates

  MCP levels of major emerging and advanced economies appear to be close together. In fact, when adjusting for stainless steel trade, cluster 1 including China, Russia, and India surpassed the chromium concentration level of domestically consumed steel of cluster 7, including the US, Japan, and South Korea on average already in 2001. Concentration in the other emerging cluster 2 and 3 are at the average level of cluster 7.

  Other advanced economies clustered in cluster 5 and 6 maintain a concentration of chromium higher than cluster 7 by a factor of two and three respectively. This gap remains when stainless steel trade is adjusted for, which suggests that other reasons, e.g., cultural influence the use of stainless steel.

  The minor differences in MCP level between emerging and advanced economies are a reflection of chromium's universal function as a corrosion inhibitor. The importance of this function both for industrial and end user applications underlines its unique status but is also the reason why it is not a specialty alloy found only in high tech products in advanced economies. Rather, in the form of stainless steel, it enjoys a wide spread distribution in all major steel producing and consuming economies worldwide, to a large extent regardless of the stage of economic development[330].

- Growth of MCP rates

  MCP rates in the China, Russia, India cluster continue to grow strongly measured both in steel production as well as in domestically consumed steel, closing the gap to major Western European countries. Particularly China's strong MCP growth rates suggests that chromium demand will continue to grow above GDP. This is turn is an indication that China's steel production is becoming increasingly sophisticated as level of chromium intensity in steel production and domestic consumption reach those of Western European countries.

  In advanced economies, growth rates of chromium intensity in steel production in advanced economies are stagnating between 1994 and 2008 for cluster 1 bundling the major steel producers USA, Japan and South Korea. Growth of chromium intensity in steel in highly specialized Scandinavian steel producers appears to be driven mainly by exports. On the other hand, the increase in chromium intensity in major Western European steel producing countries such as Germany, France, Italy and Spain appears to be driven by internal demand for stainless steel.

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330 Differences between countries of different stages of economic development can be found in the use of the type of stainless steel. Compare also chapter 6.8.2

The above analysis identified the relevant driver of growing IU following the top down logic of the intensity of use technique as depicted in Exhibit 11 in chapter 3.2.1 and helps to substantiate the influence of major industry and consumer trends deduced in chapter 6.1 on chromium apparent consumption patterns through the functions chromium effectuates in steel.

6.4 Manganese

Manganese's main use is in steel making, comprising over 90 percent of manganese used today. Manganese provides two distinct properties. During the steel making process, it is added to combine with sulfur and for its deoxidation properties, helping to remove both undesirable sulphur and oxygen. It is estimated that about 30 percent of manganese is still used for this purpose.[331] Its other property, comprising the major share of manganese used in steel is as an alloying element in steel. Manganese plays an important role in improving strength and toughness of steel. By mitigating the response of steel to quenching it helps refine steel's characteristic micro-structure known as pearlite. This virtue is the reason that traces of manganese between 0.15 percent and 0.8 percent are contained in virtually all low carbon steel grades. Higher percentage rates are found in high strength low alloy steels (HSLA) and in speciality steel grades. Furthermore, manganese is used for its ability to form an austenitic structure, as does nickel. Stainless steel containing between 4 to 16 percent of manganese, also called 200 series stainless steel, has been introduced as a low cost alternative to nickel containing austenitic stainless steel. In non-steel applications, manganese is used as an alloy in aluminum to enhance corrosion resistance as well as in copper to improve castability and mechanical strength. Its most important non-metallurgical application is as a depolarizer in dry-cell batteries, followed by the use as a chemical to purify water and treat waste water.

In the following chapter, growth in apparent consumption is decomposed into GDP, the material composition of product (MCP), i.e. manganese intensity in domestic steel production and the product composition of income (PCI), i.e. the growth of steel production relative to GDP will be analyzed on a regional basis. Chapter 6.4.2 summarizes the findings of the chapter.

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[331] International Manganese Institute (2010)

6.4.1 MCP and PCI analysis of manganese demand growth

Judging from manganese's demand profile, apparent consumption of the metal should follow the production of steel. Exhibit 40 displays apparent consumption development by cluster for the two periods from the average of 1994 to 1996 to the average of 2000 to 2002 and to the average of 2006 to 2008:

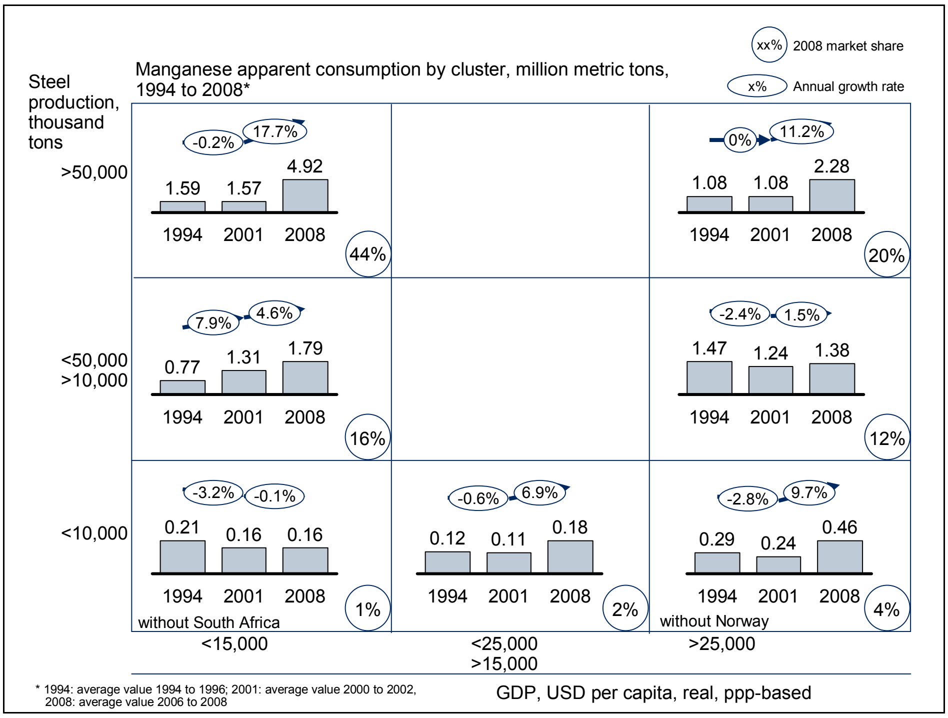

Exhibit 40 - Manganese apparent consumption growth by cluster, 1994 to 2008

Source: Own illustration

In all but one country cluster, apparent consumption stagnated or fell between 1994 and 2001 but rebounced strongly during the commodity boom period from 2001 to 2008. Cluster 1 comprising China, India and Russia experienced an 18 percent annual growth rate from 2001 to 2008 and was the major consuming cluster of manganese in 2008, comprising 44 percent of global apparent consumption. As the only cluster experiencing growing apparent consumption in the period prior to the boom cluster 2, including Brazil and Ukraine as the main manganese consuming economies, saw an 8 percent growth between 1994 and 2001 and continued to encounter growing consumption during the boom, albeit at a lower rate of 4.6 percent. In 2008 this cluster consumed 16 percent of global apparent consumption in 2008. Combined, emerging economies' share of global apparent consumption of manganese was over 60 percent.

Among advanced economies, a mixed picture emerges. In the cluster 5, growth fell from 1994 to 2001 mainly driven by falling apparent consumption in Australia, the Netherlands and Austria before returning with double digit growth rates in the latter two during the commodity boom from 2001 to 2008. Growth among Western Europe's main steel consumers in cluster 6 stagnated between 1994 and 2008. Finally, demand in the major steel producing economies USA, Japan and South Korea remained constant during the period prior to the boom and experienced strong growth at an annualized rate of 11 percent during the boom.

Over 60 percent of manganese apparent consumption is consumed in emerging economies. Major steel producing economies bundled in cluster 7 consume barely 20 percent of global demand.

To nurture a better understanding of manganese's demand development, the drivers of growth are depicted in Exhibit 41:

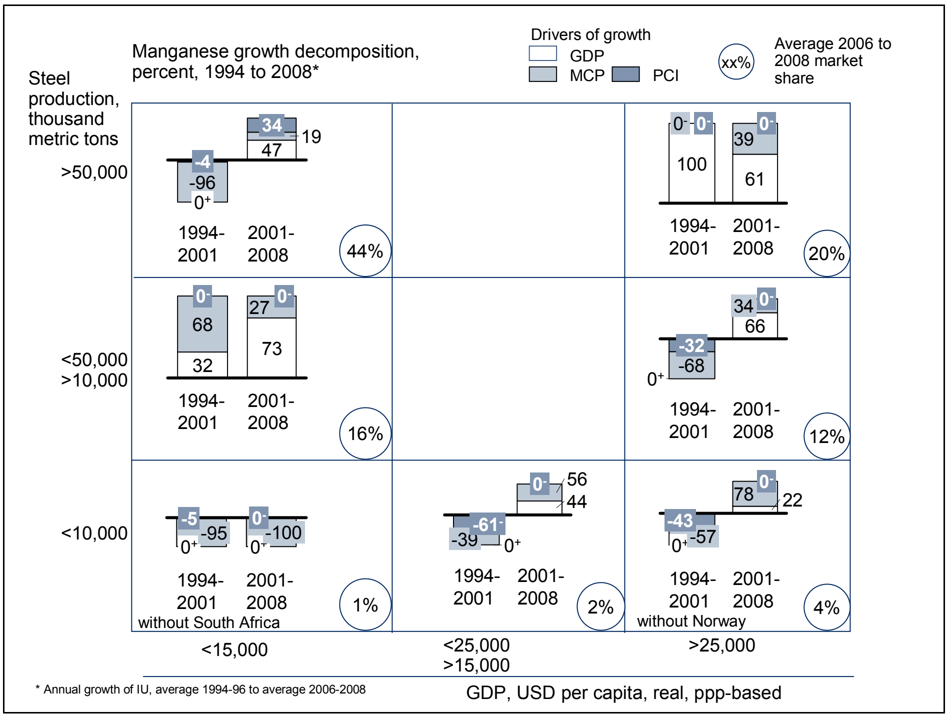

Exhibit 41 –Decomposition of demand by cluster, 1994 to 2008

Source: Own illustration

A reduction of manganese content in steel production was the major cause of declining demand during the period from 1994 to 2001 in most emerging economies, followed by fall in steel production relative to GDP. In cluster 1, 96 percent of declining demand was caused by declining manganese content in steel. Rising GDP compensated for this decline in MCP, otherwise demand would have declined much stronger. Despite strong growth in during the commodity boom, rising MCP played only a minor role, comprising 19 percent of demand growth, behind 34 percent due to rising steel production relative to GDP and 47 percent general GDP growth. This confirms the hypothesis that growth in manganese apparent consumption closely follows steel production.

In cluster 2, where demand growth remained strong throughout the analyzed periods, growth in MCP was a strong driver for growth during the first period but contributed only a minor share between 2001 and 2008, compensating for a falling steel production relative to GDP. In cluster 3, including developing Asian countries Thailand, Malaysia and Indonesia as well as Latin America's Venezuela and Chile, falling manganese content in steel production was the main driver for declining manganese demand in both periods.

In cluster 5 falling steel production relative to GDP caused 43 percent of declining manganese demand, the residual being caused by a reduction in manganese concentration in domestic steel production. In major Western European steel producers bundled in cluster 6, fall in demand during the first period can be assigned to a falling MCP rate, followed by reduced steel output. Finally, a decline in manganese content and steel production relative to GDP occurred as well in cluster 7 but was compensated by GDP growth, causing demand to stagnate. In the boom period, 39 percent of growth in this cluster can be assigned to rising manganese content in domestic steel production followed by 61 percent driven by general GDP growth.

Falling MCP rates as the main driver of falling demand prior to the boom in major manganese consuming regions are also visible in Exhibit 42:

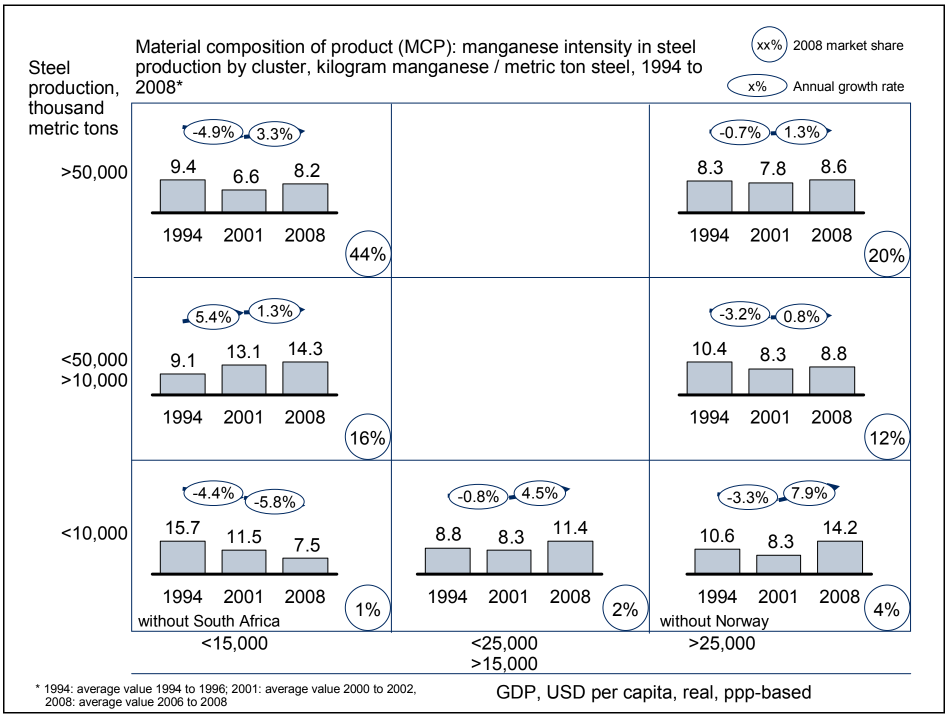

Exhibit 42 – MCP rates manganese by country cluster, 1994 to 2008

Source: Own illustration

It emerges that average MCP levels among major steel producers appear to be similar regardless of the stage of economic development. Manganese concentration for unit output of domestic steel production in 2008 was between 8.2 and 8.8 metric tons of manganese per one thousand metric tons of steel in cluster 1, cluster 7 and cluster 6, comprising economies, which consume over 75 percent of manganese.

In cluster 2, manganese concentration was rising. This effect was mainly caused by the Ukraine. Adjusting for this, MCP levels would have remained constant at 10 metric tons per one thousand tons of steel between 1994 and 2008. In cluster 3, MCP level fell steadily indicating an increasingly efficient production of steel.[332] Rising manganese concentration in cluster 5 consisting mainly of advanced economies home to highly specialized steel producers could originate from a higher functional demand for manganese's advanced alloying functions such as increased wear resistance.

In two notable cases, MCP levels vary significantly within a cluster. India's MCP level of manganese is constantly higher at around 19 metric tons of manganese per one thousand metric tons of domestically produced steel compared to 7 in China and Russia. In cluster 2,

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[332] Compare also chapter 6.8.1

the Ukraine's MCP level rose to an average of 20 metric tons per one thousand tons of steel produced. Reasons for such high rates in both countries are elaborated in more detail in chapter 6.8.1.

6.4.2 Summary

The purpose of the preceding chapter was to develop a more granular yet quantitative understanding of forces influencing the demand growth of manganese. In this context, the share and development of GDP, the material composition of product (MCP) and the product composition of income (PCI) were analyzed. Findings are summarized as follows:

- Driver of growth in manganese demand
  The major driver of declining manganese demand during the period from 1994 to 2001 were falling intensity of manganese in domestic steel production, coupled with falling steel production relative to GDP. In the years during the boom, increasing demand in the main consuming country cluster consisting of China, India and Russia was mainly caused by GDP growth, coupled with PCI, i.e. steel production outgrowing GDP followed by a slight rise in MCP rates. In major consuming advanced economies bundled in clusters 6 and 7, demand during this period grew mainly in line with GDP, bolstered by a slight increase in MCP.

- Level of MCP rates
  Among major steel producers, MCP rates appear to be in the area of above 8 tons of manganese per throusand tons of domestic steel production, regardless of stage of economic development. In selected economies, with manganese mining and refining facilities, rates appear to be higher, such as in Norway and the Netherlands as well Brazil and the Ukraine.
  Similar MCP levels in manganese between advanced and emerging economies are a reflection of the metal's unique functions as a sulfur and oxide fixing agent and as a strength improving alloy of standard grade carbon steel[333]. Both functions make it an essential ingredient to steel making and thus facilitate a wide spread distribution globally. Manganese's role in the improvement of wear resistance is important but the volume of manganese going into high alloyed steel grades is estimated to be small compared to

[333] Compare also chapter 6.1

manganese's more dominant uses[334]. A production focused on such steel grades may in part explain the higher MCP rates in selected countries.

- Growth of MCP rates
  In the analyzed time period, MCP rates fell or stagnated prior to the commodity boom from 1994 to 2001 in most major steel producing economies and grew only slightly during commodity boom from 2001 to 2008. An exception were advanced economies bundled in cluster 5. Here intensity of manganese in domestic steel production grew at a rate of over 8 percent during the boom.

The above analysis aided to identify the relevant driver of falling or stagnating IU for manganese following the top down logic of the intensity of use technique as depicted in Exhibit 11 in chapter 3.2.1. The quantitative approach complements the qualitative function based approach in chapter 6.1. The results are a reflection of manganese's universal role. Manganese's use is wide spread and its concentration in steel is saturated in most major consuming economies. In fact, a more efficient use of manganese can result in a falling concentration in steel production as is discussed in more detail in chapter 6.8.1. Both explain the similar MCP levels between emerging and advanced economies as well as the low growth rates of manganese consumption on a global scale[335].

6.5 Molybdenum

Becoming known as a replacement for tungsten in tool steel after the 2nd world war, roughly 75 percent of molybdenum is today used as an alloying element in steel or stainless steel as well as in tool steel and cast iron, where it is valued for its ability to enhance strength, hardenability, weldability, toughness, elevated temperature strength, and corrosion resistance. In this context Molybdenum is often called the energy metal due to its dominant use in steel grades for pipes and tubular goods, boilers, tanks, drilling equipment and other energy related applications. Molybdenum is used only in small amounts and rarely exceeds 2 percent of content. Molybdenum based alloys with a higher content of molybdenum enjoy growing demand linked to molybdenum's elevated temperature strength.[336] Its other major use is in catalysts (~14 percent) for the desulfurization of sour oil as well as of petrochemicals and coal-derived liquids.

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[334] Compare also chapter 4.3.2, Exhibit 15

[335] Compare chapter 5.2, Exhibit 28

[336] Imgrund/ Kinsman (2007), p.23

In the following chapter, the underlying drivers of intensity of use (IU) growth, the material composition of product (MCP), i.e. molybdenum intensity in domestic steel production and the product composition of income (PCI), i.e. the growth of steel production relative to GDP will be analyzed on a regional basis. In shapter 6.5.2 the findings of the chapter are summarized.

6.5.1 MCP and PCI analysis of molybdenum demand growth

Molybdenum apparent consumption by country cluster is displayed in the following exhibit:

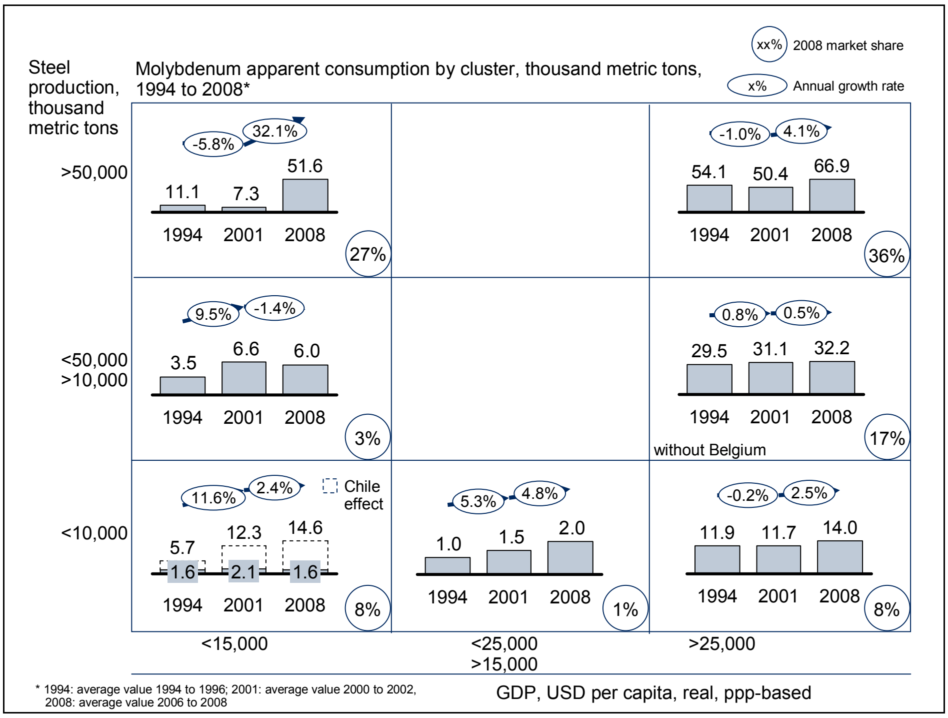

Exhibit 43 – Molybdenum apparent consumption growth by cluster, 1994 to 2008

Source: Own illustration

From the above exhibit it becomes apparent that molybdenum demand stagnated or fell in its major markets prior to the boom. Between 1994 and 2001, molybdenum's main consuming regions were traditional markets in major steel producing western economies. Here growth was sluggish. In cluster 7, comprising the US, Japan and South Korea, growth was slightly negative, in cluster 6 consisting of main steel producing Western European countries barely positive. A similar picture emerges for the lower left cluster comprising as main consuming countries Sweden, Finland, the Netherlands and Austria with Australia and Norway consuming only a minor share. Apparent consumption in major emerging economies played only a minor role in the molybdenum markets prior to the boom. Combined demand from

China, India and Russia in the cluster 1 shrank between 1994 and 2001 and comprised only 7.3 thousand metric tons in 2001, barely 7 percent of global demand. Only cluster 2 including Brazil, Ukraine, Poland, Turkey, and Mexico and cluster 3, bundling developing Asia, Chile and Venezuela experienced strong growth prior to the boom. In cluster 3, Chile as a main by-producer of molybdenum from copper production accounted for a major share of apparent consumption indicated by the dotted columns.

Molybdenum's situation changed dramatically during the period from 2001 to 2008. Apparent consumption in the upper left cluster grew by an annualized rate of 32 percent, mainly driven by China with India and Russia playing only a minor role. Within 7 years, China became a major consumer of molybdenum. Growth in advanced economies was positive during the commodity boom as well, albeit at lower levels. In cluster 7, demand grew by an average of 4 percent between 2001 and 2008, followed by moderate growth among Western European steel producers in cluster 6 and a growth rate of 2.5 percent in cluster 5. Growth in the cluster 2 fell slightly during the boom mainly because of consumption breaking off in Mexico after 2006. In contrast to chromium and manganese, cumulated consumption of advanced economies still accounts for over 60 percent of total global apparent consumption. Cluster 1 consumes only about a quarter of global consumption although exhibits the strongest growth rates, which suggests that its share is going to increase going forward.

In the following Exhibit 44 growth is decomposed by cluster into the drivers GDP, PCI and MCP:

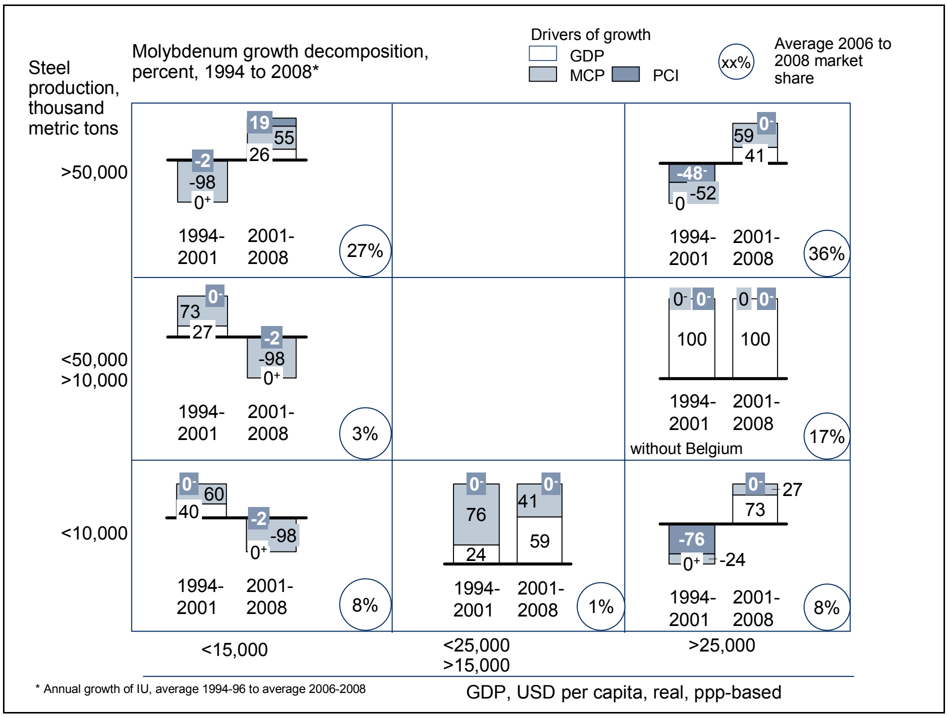

Exhibit 44 – Decomposition of molybdenum growth by cluster, 1994 to 2008

Source: Own illustration

In the major consuming markets prior to the commodity boom, located in economies with GDP per capita above 25,000 USD clustered in the right column, molybdenum consumption stagnated or fell mainly due to declining steel production and falling intensity of molybdenum in steel production. In cluster 7 combining the US, Japan and South Korea, negative growth rates between 1994 to 2001 were equally driven by falling PCI and MCP rates. In cluster 5, in which consumption is mainly driven by Sweden, Finland, the Netherlands and Austria, falling steel production relative to GDP was the main cause of stagnating demand, compensated only by positive GDP growth. Between 2001 and 2008, molybdenum demand in major steel producing economies in cluster 7 grew driven primarily by an increase in MCP rates, followed by growth in line with GDP. In cluster 5, growth was mainly in line with GDP growth and only a quarter of demand growth can be assigned to a rise in intensity of molybdenum in domestic steel production.

In cluster 1, falling molybdenum intensity in steel production in China and India between 1994 and 2001 and was responsible for 98 percent of declining consumption during that period. The extraordinary growth during the commodity boom from 2001 to 2008 was mainly driven by an increase in molybdenum intensity in steel contributing more than 50 percent of growth, followed by general GDP growth and increasing steel production relative to GDP.

Exhibit 45 complements the analysis of molybdenum growth and its underlying drivers with a perspective on the level and development of molybdenum intensity in steel production per cluster:

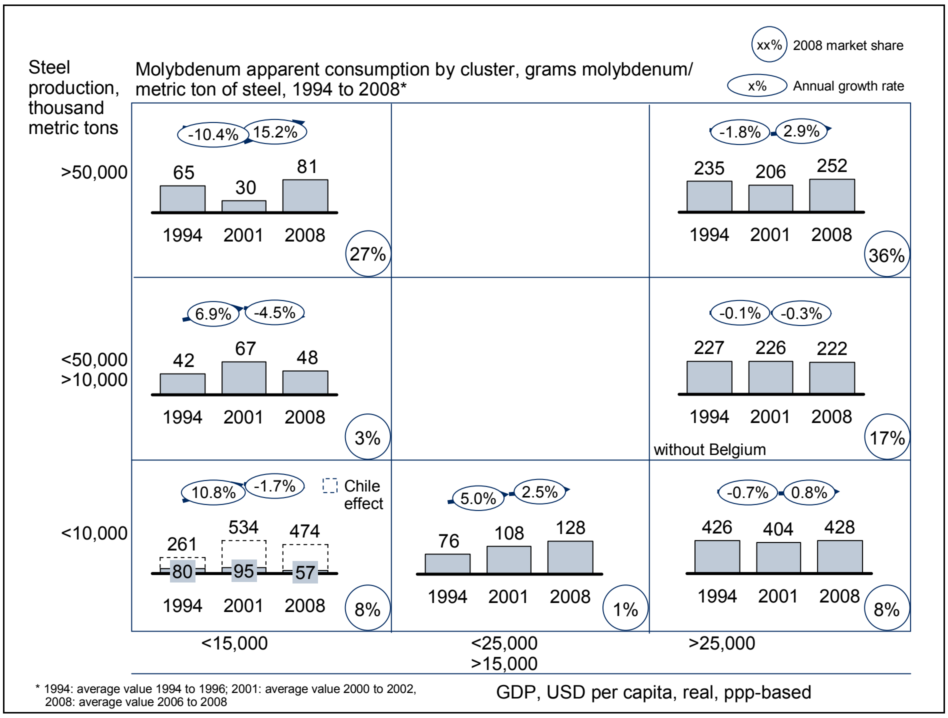

Exhibit 45 – Molybdenum MCP rates by country cluster, 1994 to 2008

Source: Own illustration

The MCP level in cluster 1 grew by 15 percent annually during the boom period despite the strong increase in steel production illustrated in chapter 6.2. In advanced economies, concentration of molybdenum per metric ton of produced steel remained relatively constant from 1994 to 2008 albeit fluctuated slightly in cluster 7 and cluster 5.

In contrast to chromium and manganese, emerging economies appear to have an overall lower molybdenum intensity per unit of domestically produced steel than advanced economies. In cluster 1, the average MCP rate is 81 grams molybdenum per metric ton of steel, roughly a third of the molybdenum intensity in advanced economies of comparable steel output in cluster 7 or cluster 6. Differences within the cluster amount, however. China's MCP rate tripled from an average 30 grams molybdenum per metric ton of steel produced between 2000 and 2002 to 93 on average between 2006 and 2008. During the same time period, India's rate fell slightly from 56 to 41, whereas Russia's MCP rate stabilized around 30 grams molybdenum per ton of steel. In cluster 7, MCP rates grew slightly, mainly driven by the US, which also had a higher MCP rate than Japan and South Korea. In the US, the MCP rate for molybdenum grew from an average of 332 grams molybdenum per metric ton of steel between 2000 and 2002 to 453 between 2006 and 2008. During that period, Japan's MCP rate grew slightly from an average of 145 to 161 and remained slightly above 80 in South Korea. In Western Europe, molybdenum intensity in steel production differs by a factor of two between cluster 6 and cluster 5. In economies belonging to the former, including Germany, Italy, Spain, Austria, UK and Canada, the MCP level remained constantly just over 200 grams of molybdenum per ton of domestically produced steel on average between 1994 and 2008. Rates differed within the cluster and ranged from an average 350 for Canada to 250 for Germany and around 200 for the remaining economies. In cluster 5, the MCP level fluctuated slightly but remained above 400. Sweden's rate was the highest with a molybdenum concentration of almost 1000 grams per metric ton of produced steel, followed by Finland and the Netherlands with rates around 550. These levels were the highest on a global scale and indicate a highly specialized steel industry in the three countries. Austria's and Norway's share of consumption in this cluster was small. MCP rates for the former fluctuated at 250, for the latter around 50. Standing out with an extraordinary high MCP level among emerging economies is Chile. The dotted column in cluster 3 illustrates Chile's effect on the cluster's average concentration of molybdenum in steel production. Chile produces molybdenum as a by-product from its copper production. Given that Chile produces very little steel and that its domestic market is unable to absorb a large amount of molybdenum, the estimated apparent consumption is probably overstated. Presumably, molybdenum is exported in forms other than the ones captured in the calculation of apparent consumption.[337]

Trade of steel and stainless steel containing molybdenum as an alloying element are not reported separately from other alloyed steel trade. An estimation how much of molybdenum apparent consumption is driven by imports and exports of alloyed steel is therefore difficult. However, trade of alloyed steel, containing also molybdenum among other alloys is reported separately from non-alloyed steel.

China's growing MCP level during the boom correlates strongly with its net alloyed steel trade development.[338] In Exhibit 46, China's MCP level development is plotted against net trade of alloyed steel in percent of total steel production. The shaded area indicates the 0.95 confidence interval of the Student's t-distribution:

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[337] Compare chapter 4.3.3

[338] Linear regression is calculated based on ordinary least square method and confidence intervals tested for the .95 percentile of the Student's t-distribution. The Student's t-distribution was chosen for its known robustness and applicability to distributions with small n. Compare also Lange et al. (1989)

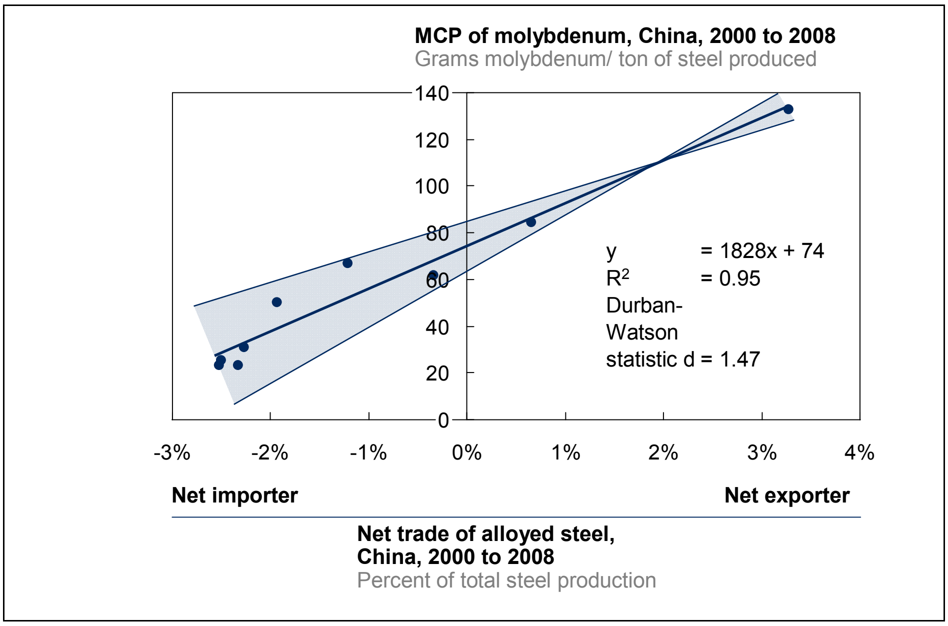

Exhibit 46 – Molybdenum MCP development of China over net alloyed steel trade relative to total steel production, 2000 to 2008

Source: Own illustration

The exhibit indicates that growth of molybdenum apparent consumption during the commodity boom from 2001 to 2008 in China strongly correlates with an increase in net exports of alloyed steel relative to total steel production[339]. Within the .95 confidence interval the regression line has an incline between 1,287 and 2,368, i.e. China's MPC rate increases by between 13 and 24 grams of molybdenum per ton of steel per 1 percent of increase in net exports. Within the same confidence interval, the regression line intersects the ordinate between 63 and 85 grams molybdenum per ton of produced steel, i.e. when trade of alloyed steel is just balanced. An MCP level above this threshold is the result of an increase in the exports of molybdenum containing alloyed steel. China's 2008 MCP value is 133, which suggests that China's alloyed steel exports contain more molybdenum than the steel consumed domestically. Assuming that the upper intersect value of 85 grams molybdenum per metric ton of domestic steel production reflects domestic consumption of China in 2008 and multiplying it with Chinese steel production of 500 million tons in 2008 yields a domestic apparent consumption of 42.5 thousand metric tons molybdenum, about 24 thousand metric tons or 12 percent of global consumption less than the calculated apparent consumption of 66.5 thousand metric tons in 2008.

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[339] The Durbin Watson value d= 1.47 is close to 2 and suggests only a mild suspicion of 1st degree autocorrelation.

The adjustment has to be interpreted with care. Alloyed steel combines a variety of steel grades, not all of which contain molybdenum. Also, the number of data points stretches only over eight years. Particularly, data for the period from 2008 onwards once available should be considered as well to test the robustness of the regression. Finally, the intersection in the above estimation of domestically consumed molybdenum is implicitly assumed to be static. Yet one would expect the threshold to shift vertically upwards over time as the nature of domestic steel demand approaches alloying levels of advanced economies, therefore the values marking the .95 confidence interval should not be used unconditionally to forecast domestic demand going forward.

It should be noted though that China's vast domestic molybdenum resources and the fact that export tariffs and quotas since 2006 put a cap on exports of molybdenum in its intermediate forms lend support to the conjecture that molybdenum exports continue channeled further down the value chain in the form of alloyed steel[340].

6.5.2 Summary

The purpose of the preceding chapter was to quantify the drivers of molybdenum demand growth beyond intensity of use. In this context, the share and development of GDP, the material composition of product (MCP) and the product composition of income (PCI) were calculated. Findings are summarized as follows:

- Driver of growth in molybdenum demand
  Molybdenum's growth since 2001 took place predominantly in China, followed by growing demand in the US. In both cases, a rise in intensity of molybdenum per ton of domestically produced steel comprised over 50 percent of growth. Growth stagnated in Western Europe's major steel producing economies and grew only slightly in highly specialized economies such as Sweden, Finland and the Netherlands.

- Level of MCP rates
  The level of MCP rates is higher on average in major steel producing advanced economies compared to major emerging economies by a factor of three. Among advanced economies, economies with specialized steel producers reach levels of MCP, which are higher by a factor of six compared to emerging economies.
  The higher concentration of molybdenum in steel production of advanced economies suggests that demand for steel grades fulfilling the functions molybdenum brings to bear

[340] Compare chapter 7.2 for further details

in steel, namely corrosion resistance and high temperature strength in combination with chromium as well as an increase of strength, is much higher relative to total steel demand than in emerging economies.

- Growth of MCP rates
  In major consuming economies MCP rates were mostly declining or stagnating prior to the commodity boom between 1994 and 2001. During the commodity boom from 2001 to 2008, rates were growing strongest in emerging countries, mostly driven by China. However, regression analysis indicates that this in part was driven by an increase in net exports of alloyed steel. Thus, levels of molybdenum concentration in domestically consumed steel are presumably lower.
  During the same period, MCP levels appeared to stagnate on a higher level in advanced economies, except in the US, where MCP levels grew at over 5 percent between 2001 and 2008.

In the above analysis the major drivers of growth of molybdenum's apparent consumption following the top down logic of the intensity of use technique as depicted in Exhibit 11 in chapter 3.2.1 were identified.

6.6 Niobium

Niobium's major use is as an alloying agent in high strength low alloy steel (HSLA) and stainless steel. The end use of steel and stainless grades using niobium is in oil and gas pipe lines, in automotive components as well as in structural components, e.g. in high rise buildings. Niobium in steel forms niobium carbide and niobium nitride, compounds which improve the grain refinement via retardation of austenite recrystallisation and the precipitation hardening of steel.[341] Small amounts of niobium, usually below 0.1 percent thus substantially increase the strength of steel, allowing the development of light weight steel grades. Furthermore, niobium leads to improved toughness, formability, and weldability of microalloyed steel.[342] In its second major use in super alloys, niobium is used as a precipitation strengthener and adds high temperature strength as well as corrosion resistance. A further use in this field is as an alloying element in superconductors.

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[341] Heisterkamp/ Carneiro (2001), p.3

[342] Patel/ Khul'ka (2001), p.477

In the following chapter, growth of apparent consumption is decomposed into GDP, the material composition of product (MCP), i.e. niobium intensity in domestic steel production and the product composition of income (PCI), i.e. the growth of steel production relative to GDP on a regional basis. Chapter 6.6.2 summarizes the findings of the chapter.

6.6.1 MCP and PCI analysis of niobium demand growth

Niobium's apparent consumption development by country cluster is illustrated in Exhibit 47:

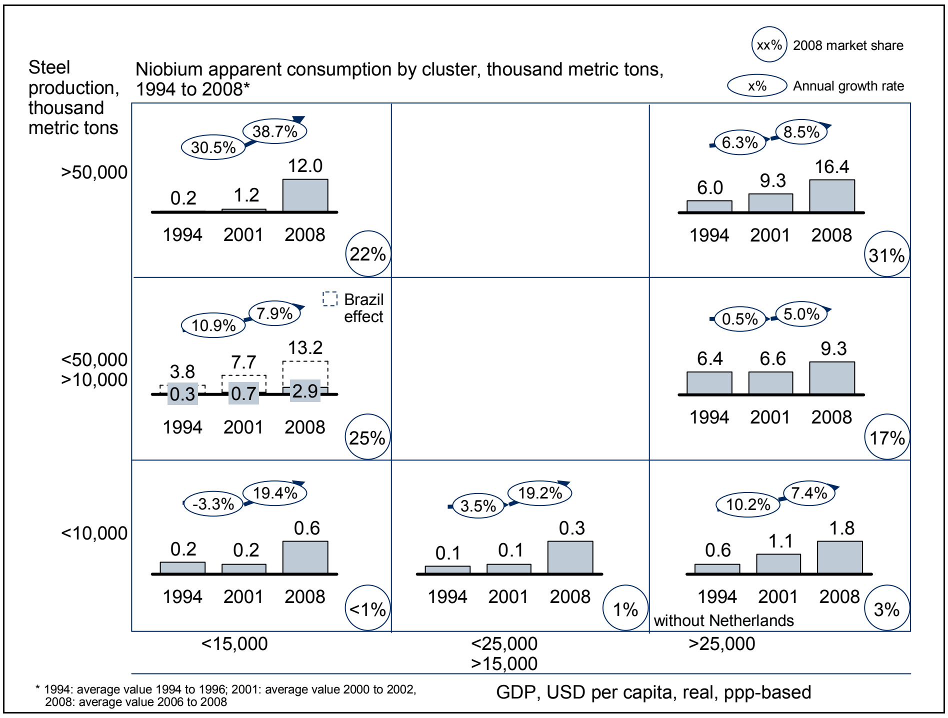

Exhibit 47 – Niobium apparent consumption growth by cluster, 1994 to 2008

Source: Own illustration

Niobium apparent consumption grew throughout the analyzed period from 1994 to 2008 in all major consuming clusters. In emerging economies, the major consuming hubs of niobium were in cluster 1 and 2, mainly driven by China and Brazil. Growth before and during the commodity boom was strong, albeit much stronger in the upper left cluster, where demand started before the boom from a much lower basis in 1994. Other emerging economies were only minor consumers of niobium.

Among advanced economies, niobium apparent consumption growth was positive prior to the commodity boom between 1994 and 2001 and growth picked up further during the commodity boom. Growth rates were strongest in cluster 7, comprising the three largest steel producers among advanced economies, the US, Japan, and South Korea, which was also the cluster consuming the major share of niobium within advanced economies. In cluster 5 including the Scandinavian countries Sweden, Norway and Finland as well as the Netherlands, Austria, and Australia niobium apparent consumption was equally strong during the commodity boom but the cluster's share of global consumption was much smaller at 3 percent on average between 2006 and 2008. Finally, growth in the major Western European steel producing economies and Canada, bundled in cluster 6 was lowest among advanced economies but still strong at 5 percent per annum during the commodity boom, comprising 17 percent of global consumption on average between 2006 and 2008.

In the following exhibit, growth is decomposed into the main growth drivers according to the intensity of use technique:

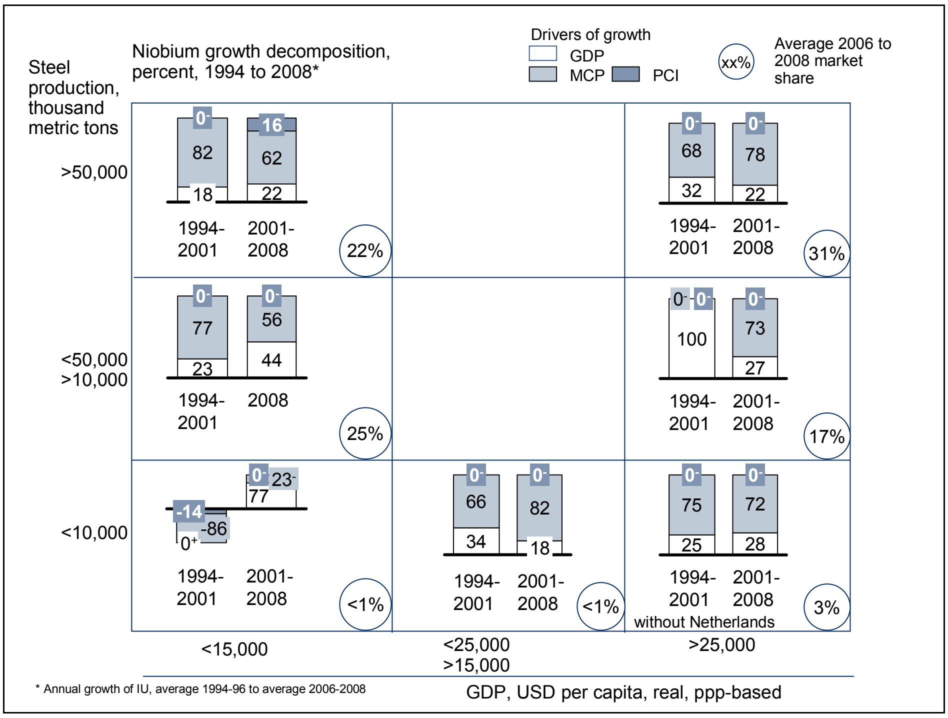

Exhibit 48 – Decomposition of niobium growth by cluster, 1994 to 2008

Source: Own illustration

It emerges that niobium apparent consumption growth in all major consuming clusters is driven mainly by an increase in MCP rates. In cluster 1, an increase in the concentration of niobium per ton of domestically produced steel comprised 82 percent of growth between 1994 and 2001 and still 62 percent during the commodity boom between 2001 and 2008. GDP and an increase in steel production relative to GDP made up the residual. A similar picture emerges for the other major consuming cluster among emerging economies on the middle left, including Brazil as the major consumer, followed by Mexico, Poland and Turkey.

Increasing intensity of niobium per ton of domestically produced steel comprised over 70 percent of growth of niobium apparent consumption in all advanced economies between 2001 and 2008, followed by general GDP growth and overcompensating for an overall decline in steel production. In cluster 7, an increasing MCP rate made up 68 percent of growth in the period prior to the commodity boom and even 72 percent in cluster 5 during the same period. In Western Europe's major steel producing economies in the middle right cluster, the MCP rate was slightly falling from 1994 to 2001 and was overcompensated by general GDP growth.

The following Exhibit 49 illustrates the development of niobium MCP rates per country cluster between 1994 and 2008:

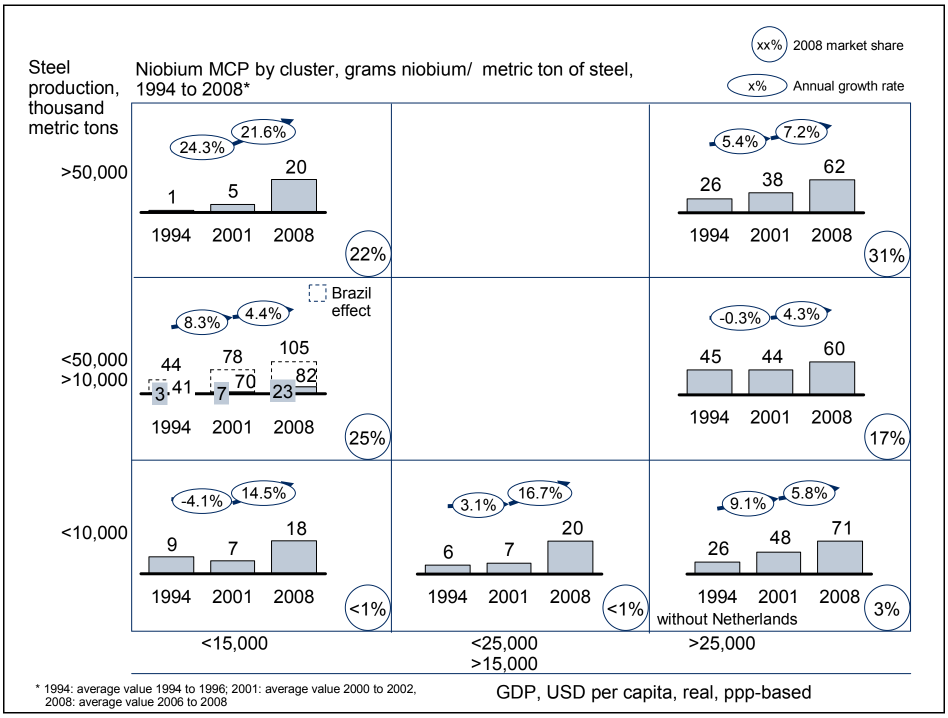

Exhibit 49 – Niobium MCP rates by country cluster, 1994 to 2008

Source: Own illustration

Several trends emerge from the above exhibit. MCP levels of emerging economies appear to converge to around 20 grams of niobium per ton of domestically produced steel on average between 2006 and 2008. Strong growth rates in MCP rates particularly in the upper left cluster, mainly driven by China suggest that this level is soon to be exceeded.

It can be shown that this strong growth is in part driven by an increase in the exports of alloyed steel[343]. Exhibit 50 illustrates that the development of China's MCP levels for niobium correlates strongly with China's shift towards becoming a net exporter of alloyed steel[344]:

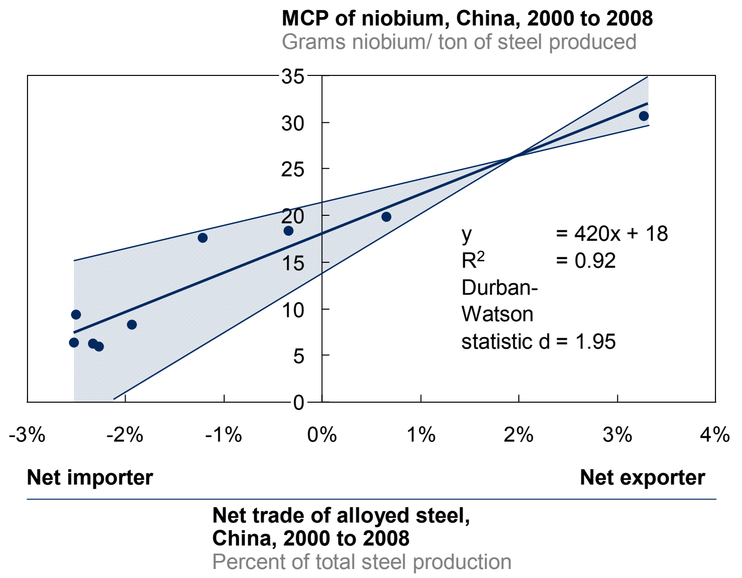

Exhibit 50 – Niobium MCP development of China over net alloyed steel trade in relative to total steel production

Source: Own illustration

The shaded area indicates the 0.95 confidence interval of the Student's t-distribution. Within this interval, China's niobium MCP level increases between 2.6 grams niobium and 5.8 grams niobium per ton of steel for each 1% increase of net exports of alloyed steel relative to total steel production. The regression line intersects the ordinate between 14.5 and 21 grams niobium. Taking the upper value as a saturation level for China's domestic demand, a concentration of niobium above 21 grams indicates that China is exporting alloyed steel with a higher niobium concentration on average than needed domestically. China's calculated MCP level for niobium based on imports and exports of ferro-niobium was 30.6 grams in 2008. Multiplying the difference to 21 grams with China's steel production in 2008 yields an amount

343 Compare also chapter 6.7

344 Linear regression is calculated based on ordinary least square method and confidence intervals tested for the .95 percentile of the Student's t-distribution. The Durban Watson value d=1.95 is close to 2 and verifies the absence of a 1st degree autocorrelation.

of niobium exported in the form of alloyed steel of 4.8 thousand metric tons or 7.6 percent of global consumption in 2008.

The same considerations with regards to the validity of such an adjustment remarked for molybdenum in the previous chapter apply to niobium. In contrast to molybdenum, China does not produce significant amounts of niobium domestically. However, since 2007 the Chinese government has levied tariffs on the export of ferro-niobium, which lends credence to the hypothesis that the flow of niobium exports is redirected towards higher value-added products such as HSLA steel grades that can be exported unrestrictedly.

Standing out with an extraordinary high niobium intensity in domestic steel production of 313 grams on average between 2006 and 2008 is Brazil, which supplies around 90 percent of global niobium. The high rate may results from Brazilian steel producers specializing in niobium intensive steel grades and super alloys but may also be an indication that niobium is exported in intermediate forms other than ferro-niobium such as ores, concentrates and niobium oxides, which are not reported on a granular enough level to be captured in the above calculation of niobium apparent consumption.[345] Thus, Brazil's apparent consumption may be overstated.

In major steel producers within advanced economies bundled in cluster 6 and 7, MCP levels are around 60 grams of niobium per ton of domestically produced steel, a factor of three larger than in emerging economies, coming from a base level of 35 grams on average between 1994 and 1996. This base level appears to have been higher by a factor of 1.5 in cluster 6, comprising major Western European steel producing economies, which may explain the slower growth in apparent consumption in this cluster compared to the upper and lower right cluster. Also, MCP rates grew during the commodity boom between 4.3 and 7.6 percent annually, suggesting that Niobium intensity in steel continues to rise. In cluster 5, the level of 60 grams was already exceeded on average between 2006 and 2008, lending further credence to the hypothesis that economies clustered here are home to steel producers focusing predominantly on specialty steel grades.

6.6.2 Summary

The purpose of the preceding chapter was to quantify the drivers of niobium demand growth beyond intensity of use. In this context, the share and development of GDP, the material

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[345] Compare also chapter 4.3, Table 17 for details

composition of product (MCP) and the product composition of income (PCI) were calculated. Findings are summarized as follows:

- Driver of growth in niobium demand
  As in most metal commodities, growth in emerging economies was mainly driven by the upper left cluster, mainly driven by China, with India and Russia playing only a minor role. Global share of global apparent consumption in this cluster rose from 0.4 percent in 1994 to 27 percent in the year 2008. Growth however was also strong in advanced economies, notably in the upper right cluster comprising the US, South Korea and Japan, where niobium apparent consumption grew by 7 percent annually on average since 1994. Overall the main driver of growth, accounting for over 50 percent of growth in all major consuming regions, was a rise in niobium concentration per ton of domestically produced steel.

- Level of MCP rates
  Emerging economies converged consistently to a level of 20 grams niobium per ton of domestically produced steel on average between 2006 and 2008. Advanced economies converged at a level of 60 grams, a factor of 3 higher than in emerging economies. In cluster 5 countries, MCP levels already reached 70 grams per ton of steel on average between 2006 and 2008.
  An exception is Brazil, whose extraordinary high rate suggests a particular focus on niobium intensive steel grades and super alloys as well as a possible overstatement of apparent consumption through lack of accounting for exports of niobium products other than ferro-niobium.
  Similary to molybdenum, niobium's higher MCP level in advanced economies suggests that the demand for the function niobium effectuates in steel, which is mainly a significant increase in strength, is much higher in advanced economies relative to total steel demand than in emerging economies.

- Growth of MCP rates
  MCP rates have grown strong in all major consuming regions since 1994. Growth picked up further during the commodity boom. In the cluster comprising China, India and Russia, growth of MCP rates was strongest at over 20 percent annually between 1994 and 2008, followed by 7 percent annually during the commodity boom from 2001 to 2008 in major advanced economies in the upper right and lower right cluster. In light of this growth, MCP levels should be expected to increase further with levels in emerging economies slowly converging with advanced economies.

Following the top down logic of the intensity of use technique depicted in Exhibit 11 in chapter 3.2.1, the major drivers of niobium's growing apparent consumption were identified, complementing the linking of niobium's demand growth to the functions the metal brings to bear as an alloy in steel[346].

6.7 Consideration of alloyed steel trade and micro trends in refractory metal markets

The purpose of the preceding chapters 6.2 to 6.6 was to decompose growth in apparent consumption for four selected refractory metals into quantifiable drivers according to the intensity of use technique. A particular focus was laid on the variable MCP. The development of the concentration of a refractory metal in steel production over time and by cluster reveals to some extent the effect of functional demand refractory metals experience as a result of the functions they effectuate in steel.

The clustering methodology developed in chapter 6.2 is based on the simplified hypothesis that the major influences of refractory metal demand are economic development and steel production. While these factors have an important effect as could be illustrated in the preceding chapters, numerous other factors may influence metal demand[347]. Especially, metal specific micro trends such as substitution may have an effect on the demand of an individual metal. While the impact of such trends is difficult to quantify, an examination is nonetheless essential for a holistic understanding of refractory metal demand. Furthermore, the use of apparent consumption is an approximation of real metal demand and is estimated based on domestic production, import, and export of refractory metals in their intermediate form. Yet refractory metals may be imported and exported in the form of alloyed steel. With the exception of chromium in stainless steel, this form of trade is not available in a granular enough form to be captured in the calculation of apparent consumption. Nonetheless, whether a country imports or exports a major share of its steel production in the form of alloyed steel may greatly over- or understate the calculated MCP level. It was illustrated in chapter 6.5 on molybdenum and in chapter 6.6 on niobium that China's rise as a net exporter of alloyed steel from 2000 to 2008 was closely correlated with a rising MCP level for these metals. Similarly, a rise in the concentration of chromium is closely correlated to net trade of stainless steel. This suggests that the rise in Chinese demand for refractory metals is not entirely driven by domestic demand but owes to some extent to an increasing export activity.

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346 Compare chapter 6.2

347 Compare chapter 3.2.4

While such close correlation only exists for China, the ratio of net export of alloyed steel relative to steel production nonetheless allows a qualitative assessment of whether an economy imports or exports a large share of its refractory metals in the form of alloyed steel or whether the MCP level reflects the domestic demand for alloyed steel of that economy.

Alloyed steel trade is to some extent reported separately from non-alloyed steel and iron. It may be clustered into three categories[348]:

- Steel and steel products classified as alloyed steel
- Steel and steel products classified as stainless steel
- Steel and steel products classified as used for oil and gas applications

The following exhibits depict average MCP levels and percentage of alloyed steel trade from 2000 to 2002 and from 2006 to 2008 by cluster:

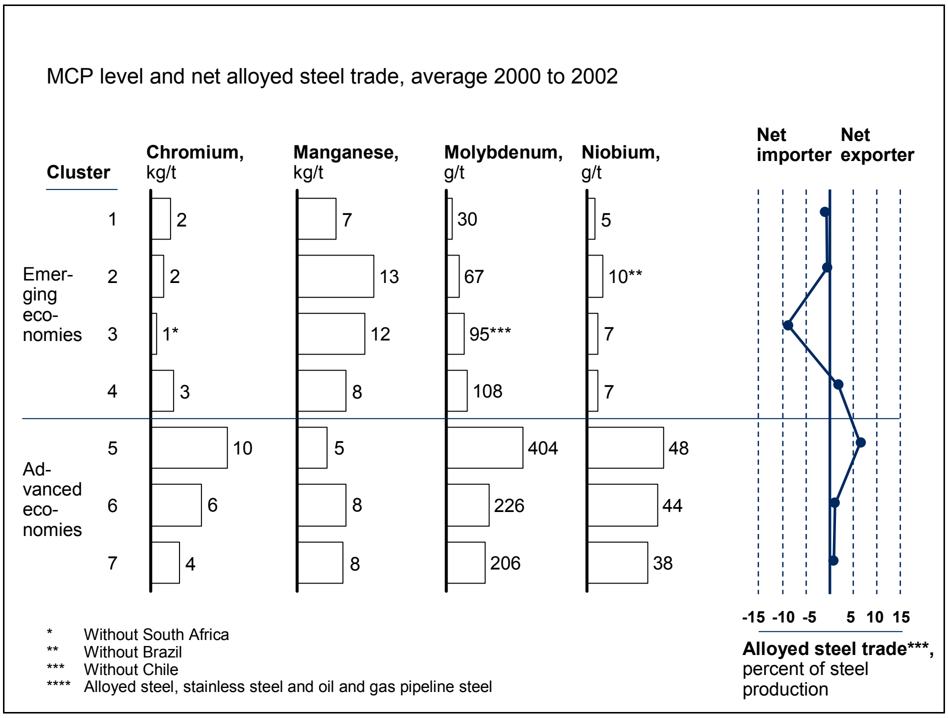

Exhibit 51 – MCP levels and alloyed steel trade, 2000 to 2002

Source: Own illustration

348 Compare Appendix, table xyz for details

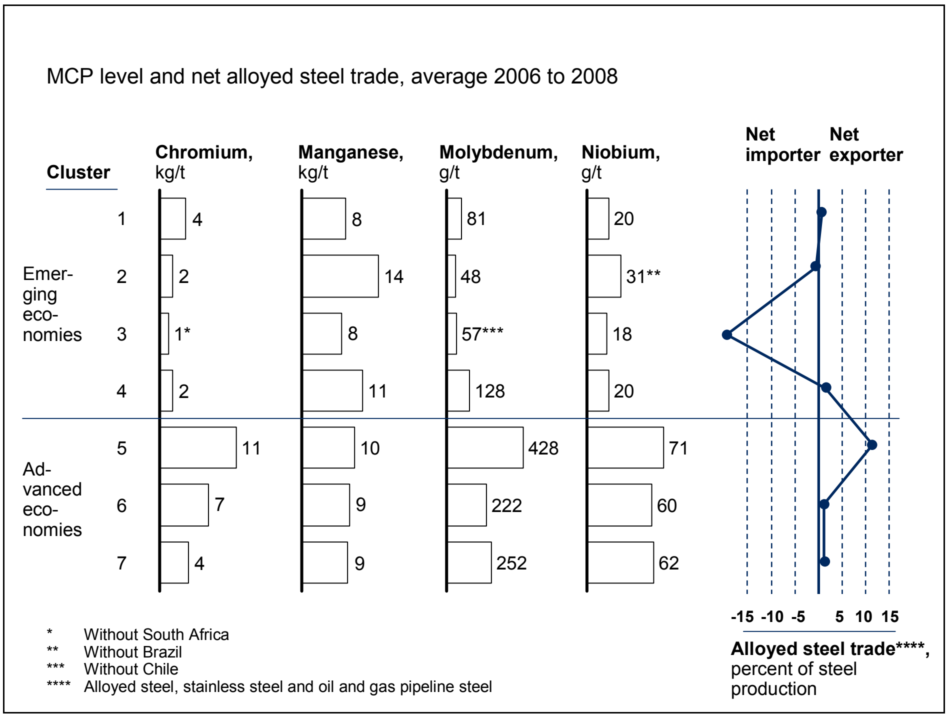

Exhibit 52 – MCP levels and alloyed steel trade, 2006 to 2008

Source: Own illustration

The exhibits illustrate that the major steel producers aggregated in cluster 1, 6 and 7 export only a minor share of their total production in the form of alloyed trade. This suggests that a dominant share is consumed domestically, although China's rising MCP levels for niobium and molybdenum from the average of 2000 to 2002 to the average of 2006 to 2008 can in part be attributed to increased exports[349]. Alloyed steel trade remained furthermore balanced during the observed time period for clusters 2 and 4, which indicates that MCP levels reflect domestic demand for alloyed steel.

Material trade imbalances exist for cluster 3 and 5. Cluster 3 aggregates economies from developing Asia, namely Thailand, Malaysia and Indonesia, which are all relying heavily on imports of alloyed steel to satisfy domestic demand. This reliance has intensified during the boom period as the average net imports of alloyed steel relative to total steel production rose from 9 percent to 19 percent. This explains in part why this cluster's MCP level are among the lowest for all metals examined. The high share of imports indicates that MCP levels of refractory metals may be understated.

[349] Compare chapters 6.5 for molybdenum and chapter 6.6 for niobium

Economies aggregated in cluster 5 are major exporters of alloyed steel on average. The average share of net exports relative to steel production rose from 6.5 percent to 11.5 percent during the observed time period, mainly due to strong exporting activities in Sweden, Finland and Austria. The heavy reliance on exports serves as an explanation for the elevated MCP levels for all refractory metals analyzed and lends support to the hypothesis that steel producers in these countries are expanding their role as global specialists of advanced high alloyed steel grades.

Expressing net exports of alloyed steel relative to total domestic steel production reveals if an economy exports or imports a relevant share of alloyed material and therefore serves as an indication whether the calculated concentration of refractory metals per ton of steel is over- or understated. It does, however, mask the share of an economy's alloyed steel trade on a global basis. The shift of economies in cluster 1 from net importers to net exporters on average appears marginal when expressed relative to total domestic production as illustrated in Exhibit 51 and Exhibit 52 but hides the magnitude of this development for global alloyed steel trade:

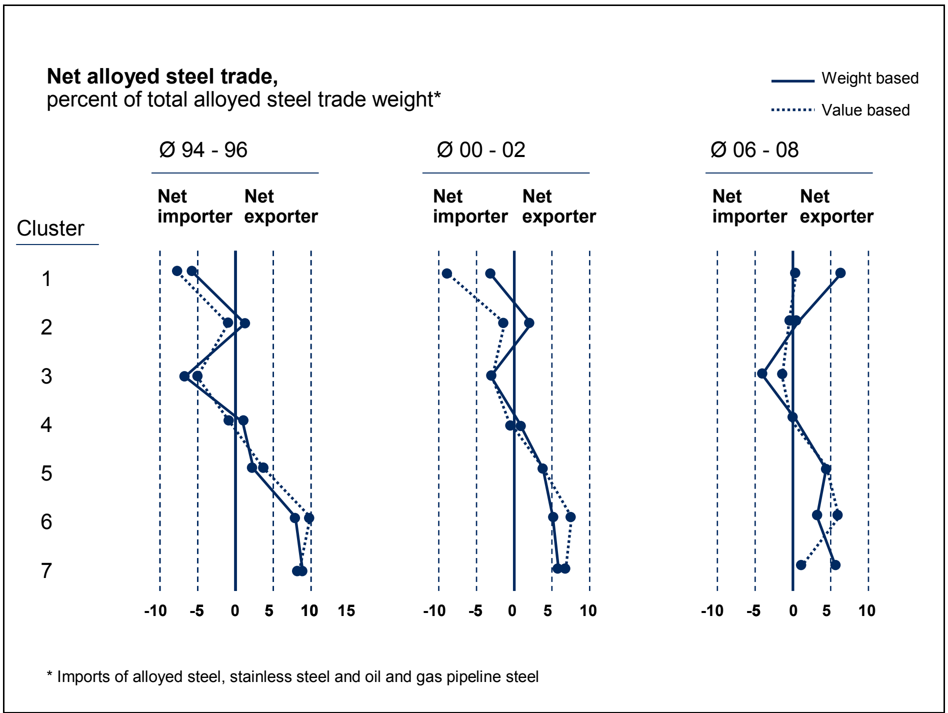

Exhibit 53 – Net alloyed steel trade relative to total alloyed trade, 1994-2008

Source: Own illustration

Exhibit 53 depicts the development of net alloyed steel trade by cluster relative to total alloyed steel trade. The solid line expresses the weight based, the dotted line the value based relationship. Throughout the observed time periods 1994 to 1996, 2000 to 2002 and 2006 to

2008, the shift of cluster 1 from a net importer to a net exporter translated into a significant change of the landscape of global alloyed steel trade. From the average of 1994 to 1996 to the average of 2006 to 2008 economies in cluster 1 rose from net importers whose net imports of alloyed steel comprised 5.7 percent of global imports on average to net exporters, whose net exports comprised 6.6 percent of global alloyed steel imports measured by weight. By value, economies in cluster 1 were marginal exporters with net exports being 0.4 percent of total imports of alloyed steel. China is the dominant driver behind this development. The fact that the value based development of net exports relative to total imports lags the weight based development suggests that a large share of alloyed steel exports is bulk material.

Whereas cluster 1 has experienced a major shift from net imports to net exports, the economies aggregated in clusters 2, 3, 4, and 5 maintained a relatively stable position. Economies in cluster 2 and 4 fluctuated mildly around a balanced trade of alloyed share. The share of net imports of economies in cluster 3 of global imports fell slightly from around 5 percent to 1.5 percent measured by value and remained relatively stable when measured by weight. Economies in cluster 5 including Sweden, Finland and Austria continued to supply a stable share of global imports of alloyed steel of around 4 percent measured both by value and weight, emphasizing their undisputed role as a global specialty steel supplier.

China's rise as a net exporter of alloyed steel during the observed time period happened at the expense of economies in cluster 6 and 7. The share of net exports relative to global imports of alloyed steel fell for economies aggregated in chapter 6 fell from an average of 9.7 percent between 1994 and 1996 to an average of 6.3 percent between 2006 and 2008 measured by value. Measured by weight, the fall was even more pronounced from 8 percent to 3 percent. The widening gap between the share of global imports measured by value and by weight is a mirror-inverted reflection of the trade development of cluster 1. During the observed time period economies in cluster 6 concentrated on exports on higher valued alloyed steel to counterbalance China's rising dominance in lower valued alloyed steel.

A different reaction to this rising dominance can be observed in advanced economies aggregated in cluster 7. Whereas the share of net exports of total global imports of alloyed steel fell both measured by value and by weight, the fall in relative value was much more pronounced during the economic boom period, from an average of 6.9 percent between 2000 and 2002 to 1.9 percent on average between 2006 to 2008. This development was mainly driven by Japan:

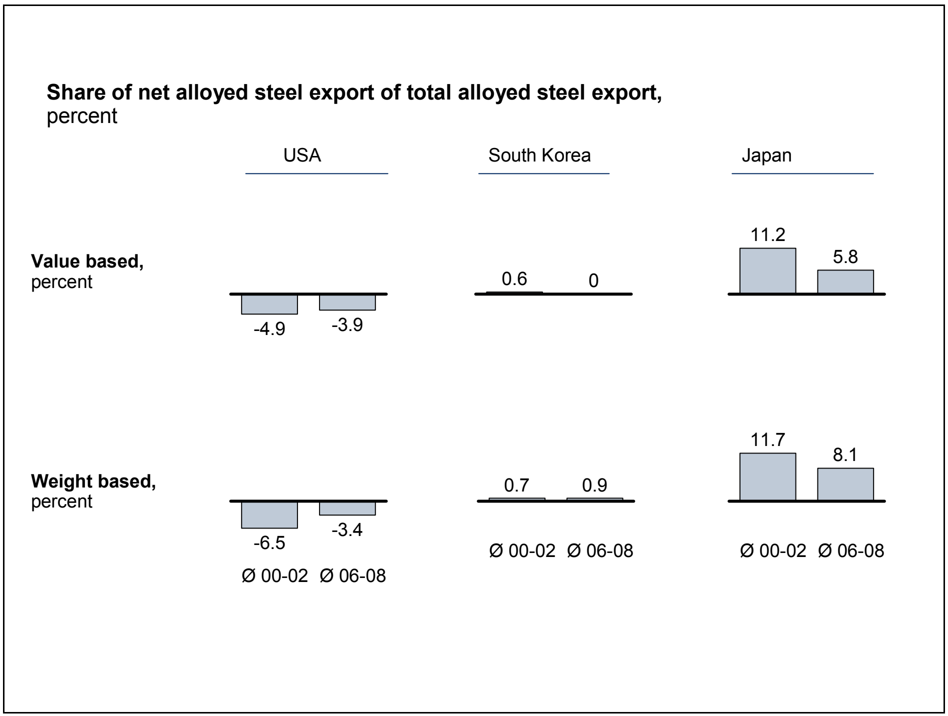

Exhibit 54 – Development of net alloyed export development relative to total alloyed trade, cluster 7 economies USA, South Korea and Japan

Source: Own illustration

Whereas the share of US net imports of alloyed steel relative to total global imports fell during the observed time period and South Korea's alloyed steel trade was roughly balanced, Japan's share of alloyed trade dropped significantly from over 11 percent to below 6 percent of total import value and to 8 percent of total import weight. Evidently, Japan failed to maintain its position in the alloyed steel market relative to global alloyed steel exports partly because it did not manage to concentrate on higher valued alloyed steel.

6.8 Analysis of metal specific developments

To complement the analysis of refractory metals in the preceding chapter 6.1 to 6.7, metal specific micro trends are examined in the following chapters as a further source of influence impacting apparent consumption.

6.8.1 Manganese

Through its universal role as both a sulfur and oxide fixing agent and as an economical alloying element to improve basic properties of steel through the refinement of steel's pearlitic structure, manganese is contained in some traces in virtually all alloyed steel grades. Thus, its role is distinct from other alloying elements that are found only in certain grades to significantly alters the properties of steel. Manganese does not visibly benefit from an increasing demand for specialty alloys caused by the general industry trends described in the previous chapter.

Its special functional role as an alloying element in steel, that is adding wear resistance to steel, is limited to a few applications, which are insignificant from a volume standpoint. On the contrary, through a more efficient steel production the amount of manganese needed per ton of steel can be reduced. The replacement of the open hearth process by the oxygen blown process and the electric furnace process reduced the intake of manganese necessary to fix sulfur and oxygen. The effect can be seen when comparing MCP levels of countries, which still use the open hearth process. In the Ukraine, 15 thousand metric tons or 41 percent of total domestic steel production were still produced using the traditional process in 2008. This share is unmatched by any other major steel producer. Ukraine's average MCP level was accordingly high. Between 2006 and 2008, the average concentration of manganese in domestic steel production was 20 metric tons per thousand tons of steel produced. To put this into perspective, Exhibit 55 shows the distribution of share of global manganese apparent consumption over manganese intensity in steel for 34 countries for the periods between 1994 to 2001 and 2002 to 2008.

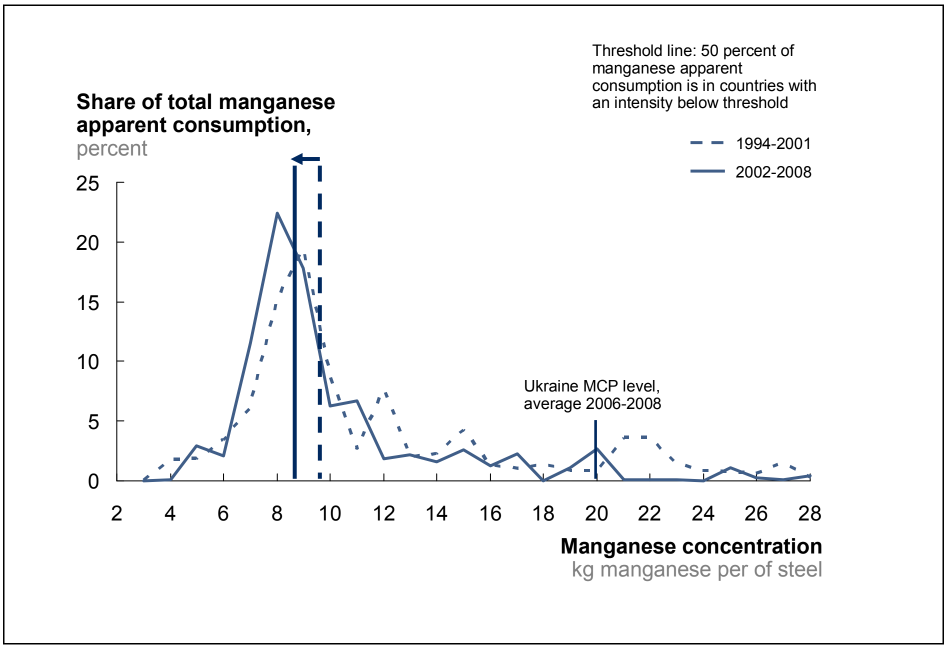

Exhibit 55 – Distribution of manganese MCP by share of apparent consumption

Source: Own illustration

For the first period, 50 percent of global manganese consumption was below a manganese intensity of around 9.5 kilogram per ton of produced steel, indicated by the dotted vertical line in the above exhibit. During the second period, the 50 percent threshold sank to 8.9 kilogram, indicating an incremental efficiency increase in the use of manganese.

Manganese's role in stainless steel has increased through its use as a substitute for nickel. Manganese containing stainless steel, called the 200 series has been introduced as a low cost alternative to nickel containing 300 series stainless steel.[350] Given the overall miniscule volume of stainless steel compared to carbon steel, the impact of this development on global manganese demand is estimated to be insignificant. It does however explain higher manganese apparent consumption in certain countries, the most visible being India. Whereas China's and Russia's MCP level appears to converge around 7 to 8 kg manganese per ton of produced steel, India's level is much higher and albeit having declined from its 1994 level still remains more than double the level observed in China and Russia.

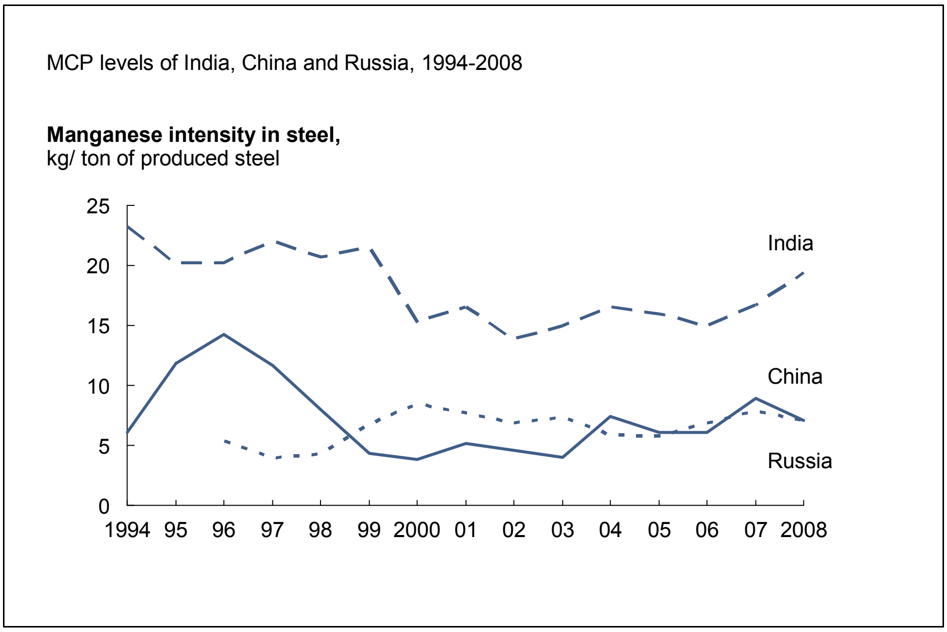

Exhibit 56 – Differences in manganese concentration in steel, cluster 1 economies China, India, Russia

Source: Own illustration

The reason for this may be explained in part by the popularity of the 200 series stainless steel. The non-magnetic property of austenitic stainless steel serves as a major quality indicator of stainless steel for Indian end consumers. As both the nickel containing 300 series and cheaper

[350] ASSDA (2006), p.1. Compare also chapter 6.8.2, Exhibit 58

manganese containing 200 series are austenitic and therefore non-magnetic, the 200 series has grown popular as a low-cost alternative to nickel containing stainless steel in kitchen ware and other end use applications, in which stainless steel plays a role visible to the consumer.[351]

Overall, growth of manganese demand is expected to follow the growth of steel. Even though evidence exists for manganese containing stainless steel having gained popularity, volumes are estimated to be too small to have a significant effect on overall manganese growth.

6.8.2 Chromium – Molybdenum

An important trend shaping the development of apparent consumption of molybdenum appears to take place in stainless steel and is therefore to some extent interlinked with chromium. Therefore metal specific trends concerning the two metals are elaborated together in this chapter.

Whereas growth in chromium apparent consumption was strong albeit volatile since 1994 apparent consumption for molybdenum stagnated till early 2000 before experiencing strong growth mainly driven by increasing demand from China:

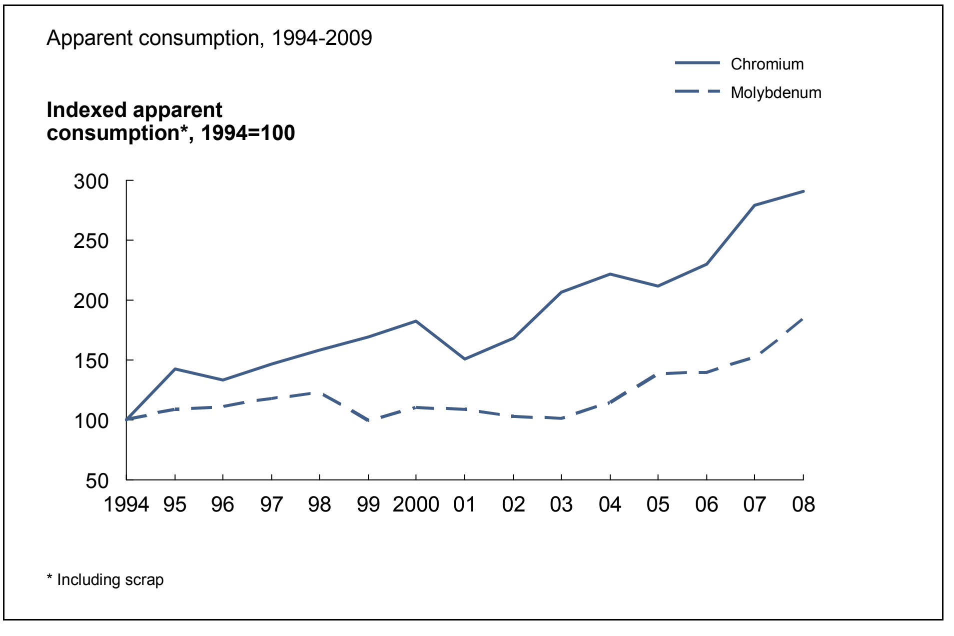

Exhibit 57 – Index apparent consumption molybdenum and chromium, 1994 to 2008

Source: Own illustration

[351] ASSDA (2006), p.2 and based on conversations with market experts

Part of this growth is due to significant changes in the stainless steel landscape during the past 10 years as already indicated in the above chapter on manganese. This is based on the intention of consumers to reduce rising stainless steel material costs and the aspiration of the stainless steel industry to meet this demand. Exhibit 58 illustrates the gradual shift between overall grad families:

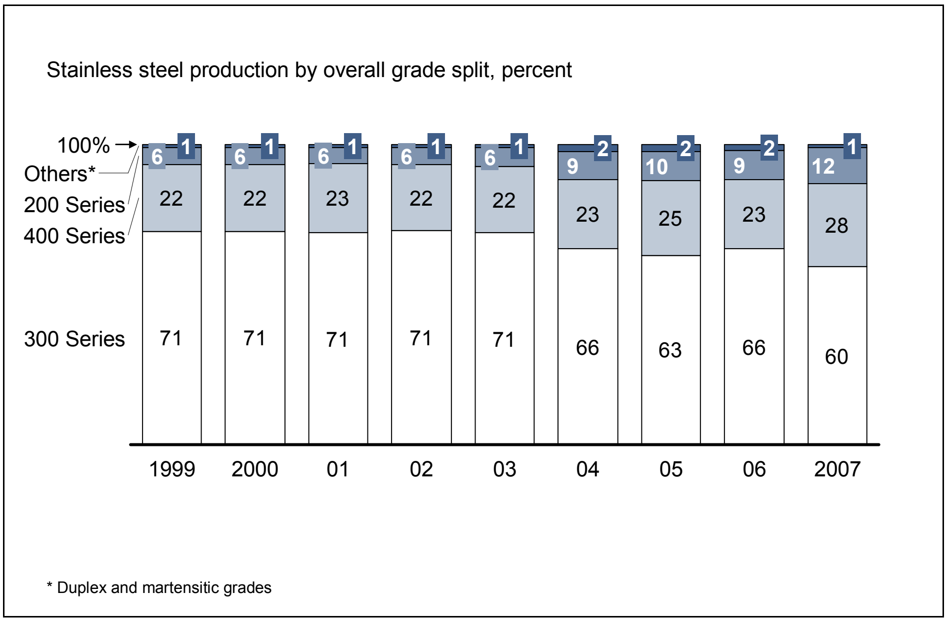

Exhibit 58 – Changes in stainless steel landscape, 1999 to 2007

Source: Own illustration[352]

Due to a continuous price rise since 1999 and an extraordinary price hike in 2007 as well as high volatility in nickel prices, which are traditionally passed on to industrial consumers of stainless steel, nickel has been identified as a major cost driver of stainless steel[353]. Efforts to replace nickel have led to a rise in 200 series stainless steel and 400 series ferritic stainless steel at the expense of a decline of the total share of nickel containing 300 series stainless steel.[354] Whereas the 200 series appears to retain an image of a low-cost and sometimes low-quality stainless steel grade family[355], ferritic stainless steel, which contains mainly

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[352] Based on ASSDA (2006); Nickel Institute (2007)

[353] International Stainless Steel Forum (ISSF) (2007), p.5

[354] 300 series: contains mainly chromium and nickel. 200 series stainless steel: contains mostly chromium and substitutes nickel for manganese. 400 series stainless steel: contains mostly chromium, less or no nickel and other alloying elements if needed such as molybdenum

[355] ASSDA (2006), p.1ff.

chromium as well as other non-nickel alloying elements is promoted as complementary and sometimes as a replacement to 300 series stainless steel[356].

While this shift away from 300 series stainless steel leaves the demand for chromium widely untouched, alloying elements in 400 series ferritic stainless steel, replacing the properties nickel provides in austentic stainless steel, benefit from this development. In this context particularly molybdenum experiences a rising use, foremost to provide corrosion resistance in grades such as 434, 444, 436 equal to nickel containing stainless steel.[357] This is reflected in a strong increase in the production of molybdenum containing ferritic stainless steel.[358]

On the back of this substitution, molybdenum together with chromium profit from a stainless steel production having continuously outgrown carbon steel since 1994, although this trend was interrupted by a fall in production during the economic crisis since 2008:

356 ISSF (2007), p.5

357 ISSF (2007), p.14

358 The IMoA reported a rise in the production of molybdenum containing grades from 47 thousand metric tons in 2002 to 360 thousand metric tons in 2005. IMoA (2007), p.22. It should be noted that molybdenum is also contained in austenitic stainless steel, foremost in a grade called 316. The substitution of ferritic stainless steel for austenitic stainless steel may therefore impede molybdenum's use for this application. As the replacement of austenitic stainless steel appears to affect mostly the dominant grade 304, which does not contain molybdenum, the negative effect on molybdenum is assumed to be marginal.

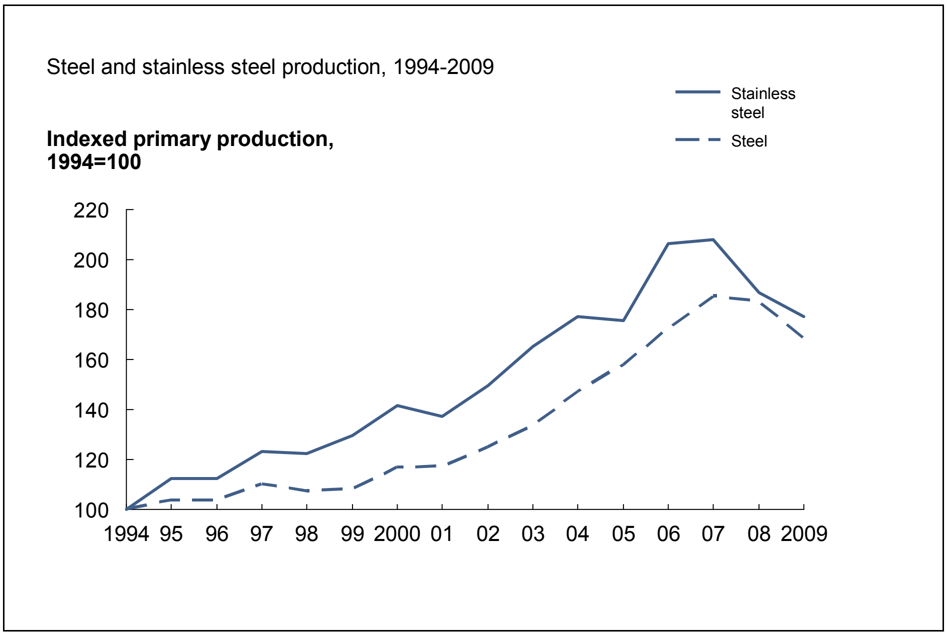

Exhibit 59 – Index steel and stainless steel production, 1994 to 2009

Source: Own illustration[359]

Part of the growth of stainless steel beyond the growth of carbon steel results from a gradual substitution of stainless steel for carbon steel in structural components[360] driven by the necessity for more corrosion resistant materials. One traditional field of carbon steel where stainless steel is newly considered is in reinforced concrete for structural components in bridges, tunnels and highways. Due to high maintenance costs for corroding constructions using carbon steel, resulting from aggressive media such as de-icing salt, stainless steel is promoted as an alternative to reduce overall life cycle costs.[361]

Finally, molybdenum is also experiencing increasing demand from its application as a catalyst. Future sources of oil are prognosed to contain increasing amounts of sulfur as sources containing sweet low sulfur crudes are depleting.[362] Molybdenum's catalytic properties are needed to desulphurize sour oil.

In summary one can assess that albeit more volatile than steel production, stainless steel production nonetheless continuously outgrew steel production since 1994, mainly driven by industry trends demanding better corrosion resisting material. Demand for molybdenum

359 Stainless steel production data: ISSF (2001 – 2008); Nickel Institute (2007) (1994-2000)

360 ISSF (2007), p.47f.

361 Gedge (2003), p.1ff.

362 Langhammer/ Zeumer (2010), p.16

strongly increased since 2003 on the back of industry trends towards higher corrosion resistance, lighter steel grades and high temperature strength as well as metal specific trends benefiting the demand for molybdenum.

6.8.3 Niobium and vanadium

Demand for niobium and vanadium are closely linked due to similar properties. Both provide a significant increase in the strength of steel and are therefore key ingredients for the development of light-weight steel for oil and gas pipelines, automotive components and structural elements in construction.[363] To some extent complements in major HSLA grades[364], where niobium acts mainly as grain refiner and vanadium mainly as a precipitation hardener[365], niobium and vanadium are also close substitutes in certain grades, although the substitution of vanadium for niobium is generally thought to result in performance penalties.[366]

Quantitative analysis of vanadium apparent consumption was dismissed due to difficulties reconciling results. Instead, production figures are plotted in the following exhibit, which are assumed to sufficiently approximate global apparent consumption:

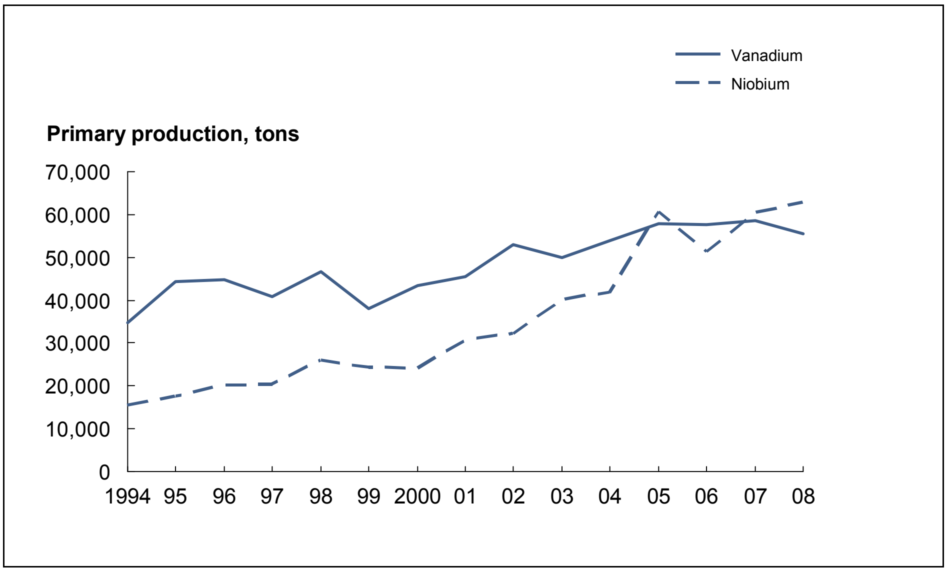

Exhibit 60 – Index production niobium and vanadium, 1994 to 2008

Source: Own illustration

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363 Mitchell (1996), p.5;

364 Heisterkamp/ Carneiro (2001), p.6

365 Patel/ Klinkenberg/ Hulka (2001), p.7

366 USGS (2010e), p.2

As illustrated in the above exhibit, production of niobium continuously outgrew production of vanadium from 1994 to 2008. In 1994, total niobium production was about 50 percent of total vanadium production volume but in 2007, niobium reached vanadium's production level and surpassed it in 2008. Assuming that recovery of niobium and vanadium in steel scrap is generally marginal due to the miniscule content of both alloys in HSLA steel grades, the production trend is a good reflection of a trend in apparent consumption. Niobium therefore enjoyed a much higher demand on a global scale than vanadium.

This development is confirmed on a regional level for the US. USGS reports US consumption figures for vanadium[367]. The concentration development of vanadium appears to resemble that of molybdenum in advanced economies. Both metals appear to have reached a level of saturation as MCP levels remained constant or grew only slightly during the observed time period:

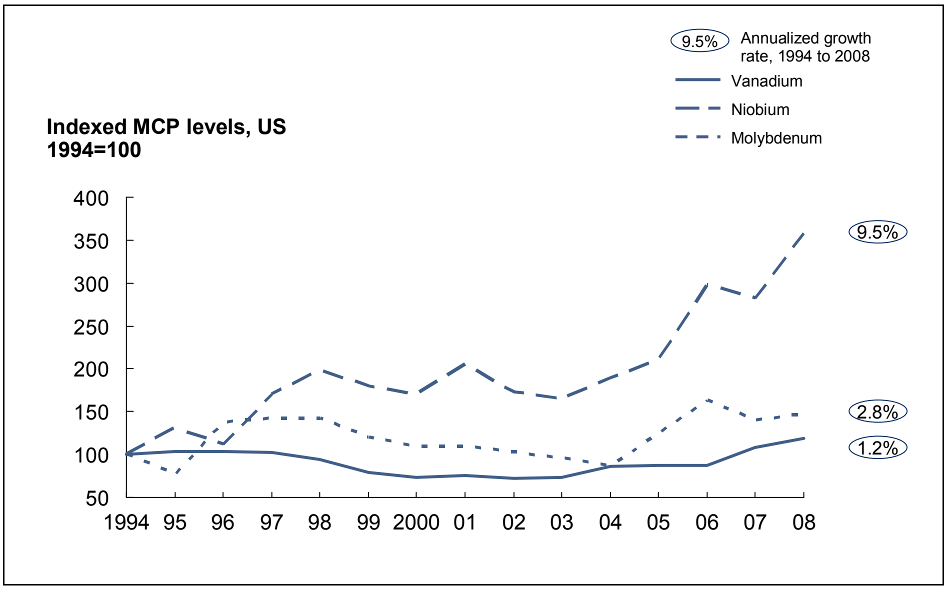

Exhibit 61 – Development of MCP levels for niobium, vanadium, and molybdenum in the US, 1994 to 2008

Source: Own illustration

Whereas the concentration of niobium in steel increased by 9.5 percent per year between 1994 and 2008, molybdenum's and vanadium's MCP rate grew only by 2.8 and 1.2 percent, respectively.

367 Vanadium consumption: 1994-1997: USGS (1999e); 1998-2001: USGS (2003e); 2002-2005: USGS (2007d); 2006-2008: USGS (2010u)

From preceding analysis it is also apparent that molybdenum's concentration per ton of steel is much higher than that of niobium. The reason for this can be found in the demand structure of the two metals as illustrated below:

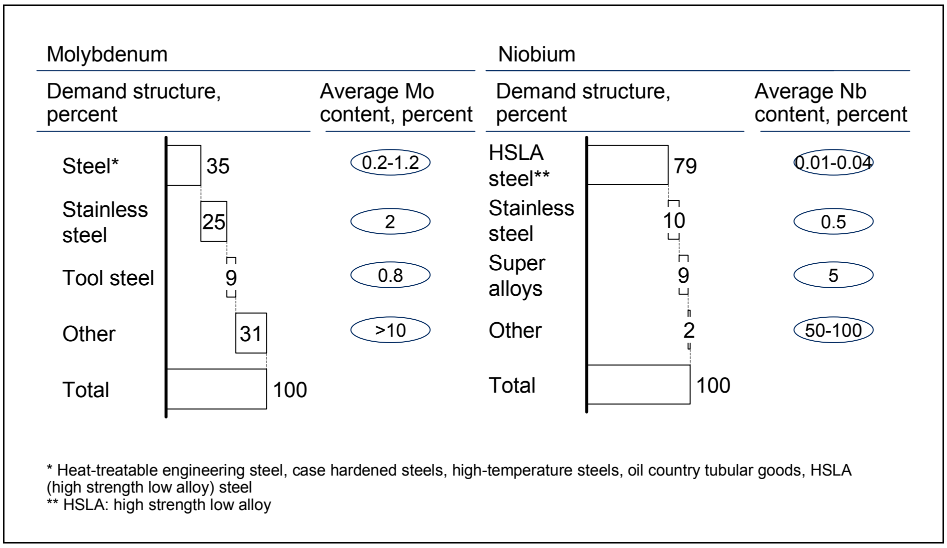

Exhibit 62 – Demand structure and average concentration for molybdenum and niobium

Source: Own illustration[368]

Molybdenum's concentration is generally higher in steel as it is not only used in HSLA steel as a microalloy but also in steel grades demanding a higher molybdenum content such as heat-treatable engineering steel, case hardened steel, high-temperature steels, and oil country tubular goods. Additionally, a higher share of total molybdenum consumption is used in stainless steel at an average content higher than the average content of niobium.

Niobium's high growth rate and increasing concentration in steel is not confined to emerging economies but takes place in advanced economies as well. This development can be attributed to two main trends favoring the use of niobium:

- Favorable properties of niobium in light-weight steel grades
- Substitution of niobium for vanadium due to economical reasons

Demand for light-weight steel grades to realize less weight and yet higher strength steel grades appears to be particularly strong in structural and automotive applications. Exhibit 63

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368 Molybdenum: IMoA (2007), p.23f.; Niobium: Companhia Brasileira de Metalurgia e Mineração (CBMM) (2010b)

provides an estimate for the development of niobium's demand share in these sectors between 1980 and 2007:

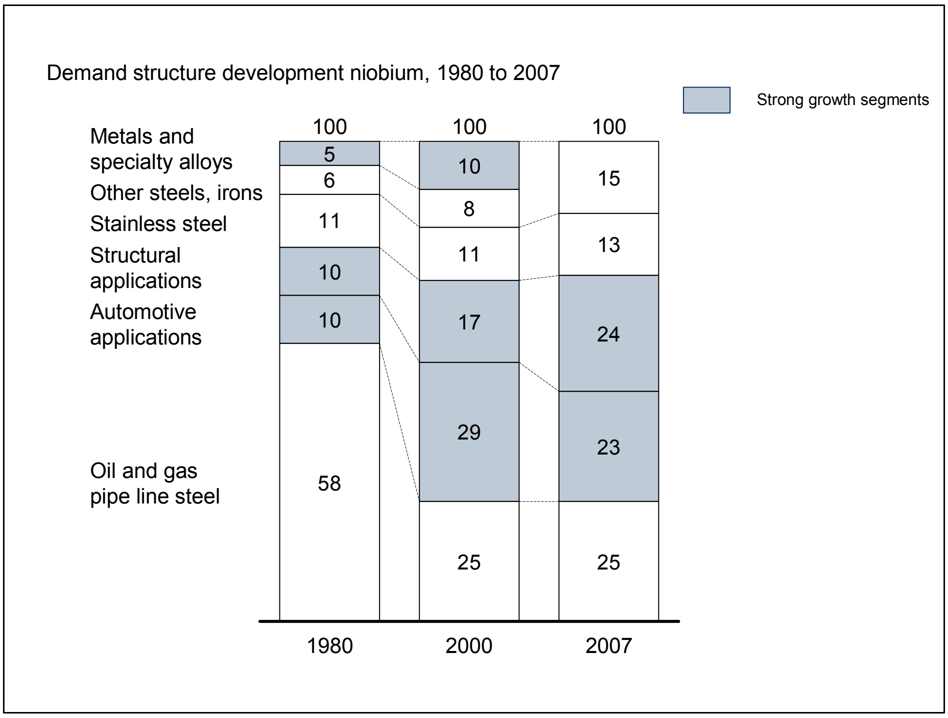

Exhibit 63 – Demand structure development niobium, 1980 to 2000

Source: Own illustration[369]

The above estimations from two different industry sources confirm that between 1980 and 2007, niobium use in its traditional application as an alloy in steel for oil and gas pipelines declined at the expense of stronger demand for niobium containing steel grades in the segments of automotive and structural components.

It is particularly the automotive sector, which has been the driver of the high profile development of niobium containing steel grades.[370] In part as a response to light-weight initiatives by the aluminum industry[371], the development of light-weight steel grades permits thinner wall thickness of car parts and consequently lower weight. In this context, a much welcomed development was the ultra light steel auto-body in the mid 1990s, which achieved a 25 percent weight reduction of the car weight on a cost-neutral basis.[372] Niobium is the alloy

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[369] 1980 to 2000: Heisterkamp/ Carneiro (2001), p.4. For 2007 compare chapter 4.3.2, Exhibit 15

[370] Patel/ Klinkenberg/ Hulka (2001), p.2

[371] Drewes/ Walker (2001), p.2

[372] Drewes/ Walker (2001), p.12

of choice due to its strength increasing properties, which appear superior to other alloying elements as less volume is needed to achieve the same yield strength:

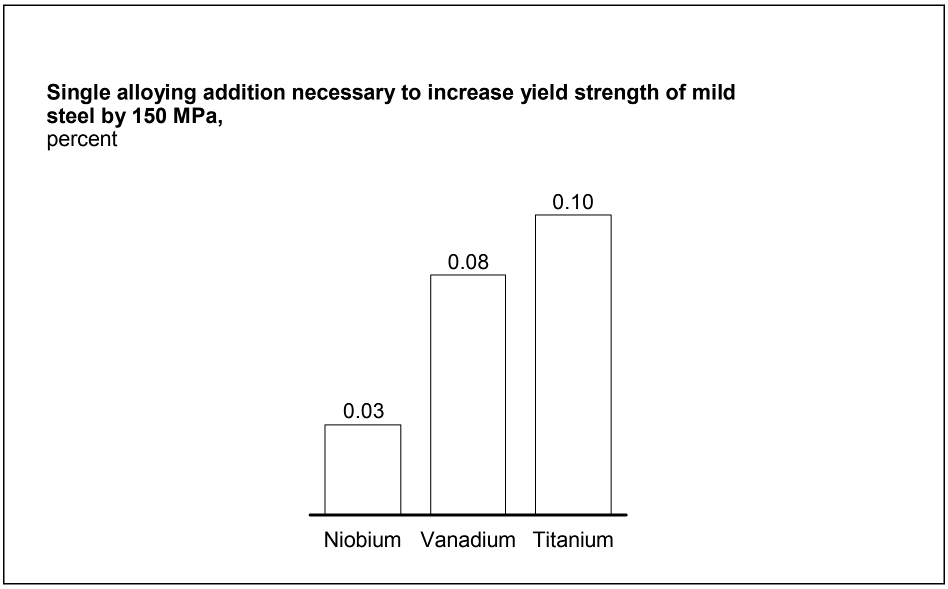

Exhibit 64 – Alloying addition necessary to increase yield strength of mild steel

Source: Own illustration[373]

A trend in HSLA steel towards lower carbon and ultra-low carbon steel grades in automotive applications to achieve better formability and deep drawing abilities also benefits the use of niobium. Lower carbon content allows an increased solid solubility of niobium in steel, causing increased precipitation hardening by niobium particles and "allows steel to accommodate a higher niobium content"[374]. Consequently, this trend is making niobium a more effective strengthener of steel.

"In modern pipeline steels, niobium is the primary strengthener and toughening agent"[375]. An increasing pipeline length to gain access to remote sources complemented by ever material challenging operating parameters such as higher pressure to raise the throughput as well as more corrosive media such as sour gas demand a relentless performance increase of pipeline steel. Niobium contributes higher strength and low temperature toughness. Lower carbon

373 Based on Patel/ Klinkenberg/ Hulka (2001), p.7

374 Tither (2001), p.7

375 Gray/Hulka (2001), p.1

content, which together with other alloying elements aims to resist corrosive media and ease weldability[376] favors the use of niobium over other alloys.

In construction, specifications favoring concrete constructions are gradually adapted to employ light-weight steel grades to reduce wall thickness, weight and handling costs.[377]

In steel manufacturing, niobium is considered advantageous compared to other alloying alternatives as it is more forgiving to alterations in processing parameters such as the cooling temperature.[378] Also, by virtue of pinning nitrogen niobium decreases the free nitrogen content, thus favoring the use of higher nitrogen containing yet more productive steel making processes as the electronic arc furnace.[379]

Aside from its favorable properties in steel, niobium is thought to have benefited from a gradual replacement of vanadium. Being close substitutes in their main application as a microalloy, the choice for niobium or vanadium is often dependent on the relative price.

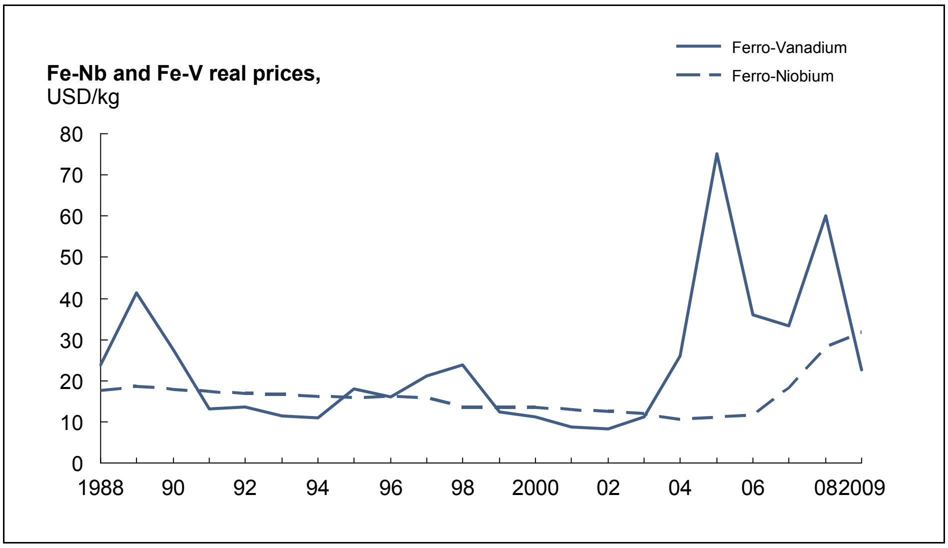

Exhibit 65 – Real price development ferro-niobium and ferro-vanadium, 1988-2008

Source: Own illustration

Exhibit 65 depicts the real price development of both metals in the form of ferro-alloys. Whereas niobium remained relatively flat since 1988 before rising in 2002 for the first time in two decades, vanadium's price has been more volatile. After peaking in 1989, prices dropped

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[376] Ibid.

[377] Donnay/ Grober (2001), p.2

[378] Patel/ Klinkenberg/ Hulka (2001), p.23

[379] Donnay/ Grober (2001), p.1

sharply before peaking again 10 years later and reached a record price level in 2005. The reason for the difference in price development lies in different price setting mechanisms. Niobium's price is set by its dominant producer, CBMM, who held it constant despite rising consumption of niobium. Vanadium's price is negotiated between major consumers and producers on a quarterly basis.

The volatile price performance and the higher amount of vanadium needed compared to niobium to achieve similar properties are named the key reasons for a gradual substitution of vanadium for niobium and combinations of niobium and titanium. Exhibit 66 illustrates the development of niobium and vanadium content by end application:

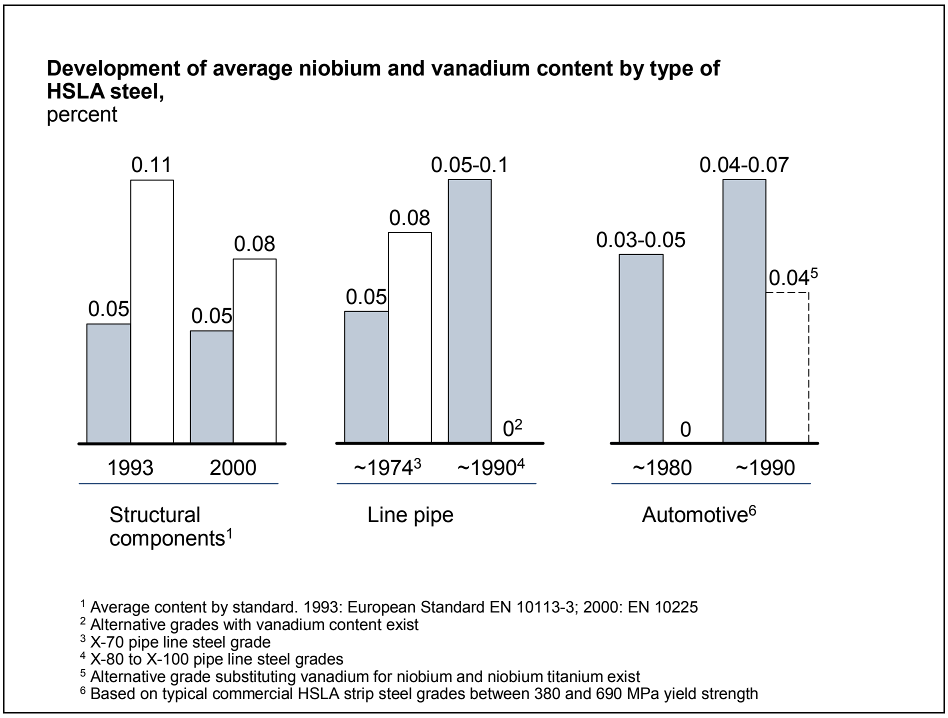

Exhibit 66 – Development of niobium and vanadium content by application segment

Source: Own illustration

For HSLA grades typically found in structural components, vanadium content dropped in modern grades as lower carbon content increases the efficiency of niobium as a strengthener[380]. While this constitutes a substitution, niobium does not visibly profit from it as the niobium content remained constant. In line pipe steel grades, the substitution is particularly visible. The X-70 grade, which was developed in 1974 and is still considered "the

[380] Grober/ Donnay (2001), p.4

work horse grade"[381] among pipeline steel grades, contains vanadium in its original specification. However, the alloy design was changed after vanadium's price peak in the late 1980s[382] and "the precipitation hardening effect due to vanadium-carbonitride was replaced by dislocation strengthening."[383] In steel grades typically used in automotive application, niobium is the primary alloy used. While grades containing vanadium exist, the alloy has so far not benefited from the extensive growth of HSLA steel in the automotive segment, suggesting that alternative grades replacing vanadium with niobium or with a combination of niobium and titanium fare better.

It should be noted that research on substitution suggests that whether a material is substituted for another does not depend solely on the relative price but also on the cost share of the material relative to total cost of the end product.[384] Given the miniscule amount of alloys in HSLA steel grades, the material cost of alloys is assumed to be marginal. Therefore, the superior performance of niobium both in the manufacturing process as well as in the end product are likely to be important reasons for niobium's stronger growth.

6.9 Summary

The purpose of chapter 6 was to develop a thorough understanding of the underlying factors influencing the development of refractory metal demand.

In a first step, demand was related to the functions refractory metals effectuate in steel. It was demonstrated that different refractory metal have differing functional profiles. Demand for these functions was identified to be effected by four major industry and consumer trends:

- Performance increase through
    - Advancement of operating parameters
    - The development of light weight high strength steel grades
- Quality improvements
- Operation in more corrosive environments

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[381] Heisterkamp/ Carneiro (2001), p.6

[382] Gray/Hulka (2001), p.3

[383] Heisterkamp/ Carneiro (2001), p.6f.

[384] Tilton (1983), p.1ff. Compare also chapter 3.2.1.1

While these trends are not new, they are accelerated by a rising prosperity and the installation of a state of the art industrial infrastructure in emerging economies, the growing aspiration globally to respond to climate change issues by developing sustainable industry solutions and consumer end products and to respond to tighter environmental standards as well as by other regional differences. E.g., in China, constructions in more corrosive environments due to a proximity to sea water or pollution effects create a strong demand for steel grades able to withstand this environment. In advanced economies lowering the weight of a car body results in higher demand for light-weight steel grades.

The quantitative effect of a refractory metal's functional profile on its apparent consumption development was demonstrated in a next step. Growth of apparent consumption was decomposed into growth shares attributable to GDP, product composition of income (PCI), i.e. growth of steel production relative to GDP and material composition of product (MCP), i.e. the refractory metal's concentration per unit output of steel production for two periods spanning the time before the commodity boom from 1994 to 2001 and during the boom from 2001 to 2008. To address potential fluctuations in the development of apparent consumption due to lack of adjusting for stock changes, growth rates were annualized based on three year moving averages. Development of MCP level as the metal dependent variable was examined in details to find evidence for a quantitative reflection of a metal's functional profile.

Specifically, 34 economies were clustered in a matrix of economic development and steel production, the latter being the dominant use of the refractory metals in focus. This aggregation yielded 7 clusters, of which cluster 1, 5, 6, and 7 comprise the major consuming economies:

- Cluster 1 aggregates the major steel producers among emerging economies, namely China, India and Russia. Due to its sizable steel production that dwarfs the ones of Russia and India as well as its outstanding economic growth, China was the dominant driver in this cluster.
  The characteristics of this cluster were strong growth in apparent consumption driven mostly by a rising concentration of refractory metals in steel, which has led to a dominant share of global apparent consumption being consumed here. Average MCP levels between 2006 and 2008 for molybdenum and niobium were below those of advanced economies by a factor of three, but at a similar level for chromium and manganese.
  Relative to domestic steel production, trade of alloyed steel appeared to be balanced between 2006 and 2008. However, measured relative to global exports of alloyed steel, China has switched from being a net importer to becoming a net exporter of alloyed steel. This rise is correlates very closely with a strong rise in MCP levels of molybdenum and

niobium, which indicates that part of the consumption of these metals is exported in the form of alloyed steel rather than used for domestic consumption.

- Cluster 2 comprises emerging economies with steel production volume comparable to major Western European producers, namely Brazil, Mexico, Turkey, Poland, and the Ukraine. Between 2006 and 2008, average adjusted concentration of chromium in this cluster was below that of cluster 1 but almost double for manganese, partly driven by inefficient steel processing found in the Ukraine. Molybdenum and niobium MCP levels were among the lowest globally. As average alloyed steel trade is balanced, the low concentration levels of chromium, molybdenum and niobium reflect the developing status of the clustered countries.

- In cluster 3, developing Asia including Thailand, Malaysia, Indonesia, Chile and Venezuela as well as South Africa are bundled together. Concentration of manganese reached the levels of cluster 1 as well as of advanced economies on average between 2006 and 2008, coming down from a much higher level before the boom.
The economies in this cluster are importing a large share of alloyed steel relative to domestic steel production on average and this trade imbalance exacerbated during the boom. In combination with a relatively low developing status and with the exception of South Africa, this is reflected in concentration levels of chromium, niobium, and molybdenum that are among the lowest globally. Adjusted for stainless steel trade, chromium concentration is at par with clusters 2 and 4. South Africa's molybdenum levels are higher due to strong imports of the metal.
Overall, economies in cluster 3 are minor consumers of refractory metals as alloyed steel is largely imported.

- Cluster 4 consists of Portugal, Argentina, Hungary and Czech Republic with Portugal being the only advanced economy. Alloyed steel trade of the four economies is balanced on average, which suggests that MCP levels reflect concentration found in domestic steel consumption. The average level of manganese are at par with advanced economies as well as cluster 1. Chromium concentration is below levels of advanced economies and similar to clusters 2 and 3. Molybdenum levels are higher than in other clusters comprising emerging economies but about half the concentration found in advanced economies. Niobium levels are at a similar level with clusters 1, 2, and 3. Overall, economies in this cluster are minor consumers of refractory metals due to a small steel production volume.

In Cluster 5, 6 and 7 the relevant consumers among advanced economies are aggregated.

- Cluster 5 includes the Scandinavian countries Finland, Sweden and Norway as well as Austria, the Netherlands and Australia. The cluster is characterized by the highest average concentration of chromium, molybdenum and niobium worldwide, which reflects a highly specialized steel production predominantly located in Sweden, Finland and Austria. The fact that economies in this cluster have successfully managed on average to defend their stable share of alloyed steel exports against rising competition from China is a further sign for the distinctiveness of the steel production located here. The MCP level of manganese is the highest among clusters of advanced economies. In light of the advanced steel production found in this cluster, this is thought to be driven by manganese's function of improving wear resistance rather than by an inefficient steel production.
- Cluster 6 comprises economies with a medium sized steel production including Germany, France, Spain, Italy, and Belgium as well as Canada. For chromium, MCP levels were between cluster 5 and cluster 7. Given that average alloyed steel trade is balanced relative to total steel production, this is thought to reflect cultural differences regarding the use of stainless steel, especially compared to the US. Otherwise, MCP levels were similar to cluster 7. For chromium, molybdenum and manganese, MCP levels were mostly stagnating during the observed time period but rising for niobium. Concentration of molybdenum and niobium in steel were higher by a factor of 3 compared to the average in cluster 1. Global share of net exports relative to total global imports of alloyed steel fell during the observed time period. A widening gap between the alloyed trade measured by value and by weight suggests that main steel producers located in countries aggregated in cluster 6 are concentrating increasingly on higher valued steel grades and slowly abandon the market for lower valued bulk material.
- The US, Japan and South Korea are aggregated in cluster 7. Levels of chromium remained below that of all other major consuming clusters including cluster 1, thought to also stem from a preferred use of aluminum over stainless steel compared to economies in cluster 6. Otherwise, levels were similar to cluster 6 and rose significantly only for niobium. During the boom, the share of net trade relative to total global trade of alloyed steel dropped significantly both measured by weight and value but more pronounced for the latter. This development originated in Japan and suggests that Japanese steel producers have not maintained their market position against China across the bandwidth of lower and higher valued steel grades.

Furthermore, metal specific factors influencing the demand development of refractory metals beyond major industry and consumer trends as well as regional trade patterns were examined.

Specifically, substitution dynamics in the markets for chromium, molybdenum, and niobium were identified to favor the use of these three metals. Manganese's concentration was found to fall marginally due to further efficiency increases of steel production processes.

Based on the consumption development, the refractory metals chromium, manganese, molybdenum, and niobium can be classified as follows:

- **Universal alloys**
  Manganese and chromium may be considered universal alloys on a global scale. Similar MCP levels adjusted for stainless steel trade in chromium in all relevant consuming clusters regardless of the stage of economic development suggest that these alloys enjoy a wide spread use. While economies bundled in cluster 5 and 6 maintain a slightly higher concentration level in chromium, emerging economies have caught up with MCP levels of major steel producers in advanced economies, specifically the US. Increase in MCP level slowed down during the boom and comprised less than 50 percent of total consumption growth during the economic boom from 2001 to 2008 in all clusters. This indicates that if levels continue to increase, this will happen only slowly.
  However, important differences abound. Chromium is the key corrosion inhibitor in stainless steel. In this unique function, for which no substitute exists, the metal experiences increasing global demand driven by trends to operate at more advanced parameters and in increasingly corrosive environments. Furthermore, stainless steel is considered a substitute for steel in certain applications. Demand for chromium is therefore expected to grow above the rate of steel production.
  Manganese is used as a cost efficient alloy in most steel grades as well as a sulfur and oxide fixing agent. With regard to the latter use, efficiency increases in steel production continue to reduce the amount of manganese necessary to produce a ton of steel and the concentration of manganese per ton of steel in emerging economies aggregated in cluster 1 is now similar to those of advanced economies. As its dominant use is tightly linked to the production of steel, manganese is expected to grow in line with steel.

- **High tech alloys**
  Compared to the universally applied alloys chromium and manganese, molybdenum and niobium are considered high tech metals. While growth in apparent consumption was strongest in emerging economies, MCP levels are still higher by a factor of three in advanced economies, which suggests that the functional profile these metals effectuate in steel are sought after mainly in advanced economies relative to total demand for steel. Adjusting Chinese MCP levels for the consumed volume estimated to be exported in the form of alloyed steel, the concentration difference between major emerging and advanced

economies is even larger.[385]

However, MCP levels for molybdenum in advanced economies stagnated between 1994 and 2008, which implies that further growth in these economies will be in line with steel output. Growth beyond the production growth of steel will mainly take place in emerging economies.

Niobium on the other hand has gained a role as the alloy of choice for the development of light weight steel grades. Through this function, the concentration of niobium in steel is rising not only in emerging economies but also in advanced economies.

The fact that large differences in MCP levels still exist as well as the important role these metals enjoy in modern steel grades largely undeterred by threats of substitution indicates that the strong demand growth these metals experienced since early 2000 will continue as the gap between emerging and advanced economies narrows. Demand for niobium will be further accelerated by an increasing concentration in steel production in advanced economies.

Growth of apparent consumption of chromium, manganese, molybdenum, and niobium was successfully linked to the individual functional profiles inherent in these refractory metals. Furthermore, regional differences were explained in the context of the developed clustering methodology accounting for stage of economic development and steel production volume as well as by considering alloyed steel trade as a third dimension.

[385] Compare chapter 6.5 and chapter 6.6 for details.

7. Consolidation of structural forces in integrated framework

The purpose of this chapter is to integrate conclusions of the preceding chapters 5, 6, and 7 into a framework that maps all crucial structural forces on the supply and demand side, which have a profound impact on the long-term level and volatility of metal prices. Within these forces, differences between non-ferrous base metals and refractory metals are highlighted (chapter 7.1). To illustrate the framework's practicability and to provide an example for supply side structural changes with a profound impact on long-term metal price as a consequence of the crisis, the framework is applied to the molybdenum market (chapter 7.2).

7.1 Consolidation of structural factors in an integrated price framework

Economic theory states that demand and supply factors are mutually the key influences of the price finding process. However, it has already been shown that structural changes on the supply side are to be differentiated between forces influencing the supply security, availability and volatility as well as forces impacting the cost position of the marginal supplier[386] that marks the break even point within the supplying industry. Additionally, the structure of the market organization at the interface of supply and demand is a further dimension influencing price volatility.[387]

Furthermore, the comparison of structural factors of non-ferrous base metals and refractory metals in chapter 5 yielded important differences on the supply and demand side. The influence of a refractory metal's functional profile as well the role of alloyed steel trade on the individual demand development beyond stage of economic development was elaborated in chapter 6.

Accordingly, an integrated framework covering the structural forces potentially impacting metal price level and volatility consists of four dimensions as illustrated in the following exhibit:

[386] Compare chapter 4.1.2, Exhibit 12

[387] Compare chapter 3.1.3

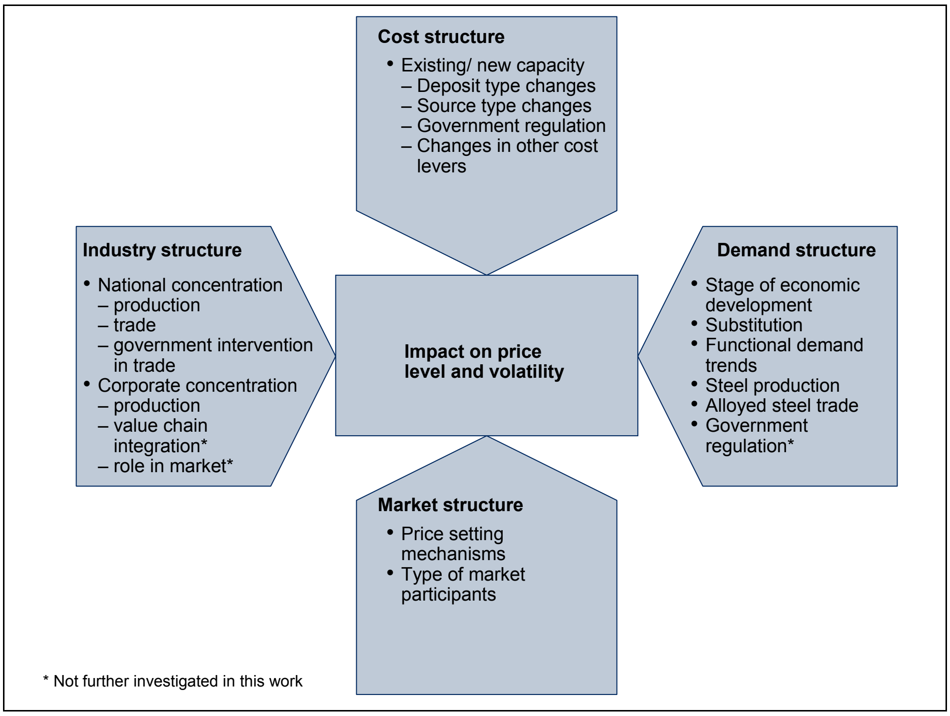

Exhibit 67 – Integrated structural metal price framework

Source: Own illustration

In the following paragraphs, the structural forces industry, cost, demand and market structure and their impact on price level and volatility are discussed. The angular arrows illustrate interdependencies across the dimensions. Government intervention is explicitly considered not as a separate force but through its impact along the four forces in accordance with an approach suggested by PORTER: "For the purpose of strategic analysis it is usually more illuminating to consider how government affects competition through the five competition forces than to consider it as a force in and of itself"[388].

- **Industry structure**

  National concentration in metal production was long thought to be of dwindling importance for the issue of resource security and price level in times of globalization and open trade.[389]

  Yet the national concentration of refractory metals' production is generally higher than of non-ferrous base metals. Combining this observation with a perspective on the concentration of actual trade in refractory metals and assessing the trade openness of China as a major exporter of selected refractory metals illustrates that a major share of

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[388] Porter (2004), p.29

[389] Porter (1986), p.4

trade is subject to constraints with potentially severe implications for regions relying on imports of these metals in their intermediate forms. One concrete implication of Chinese metal export restrictions is a shift of exports further down the value chain. Specifically, the rising concentration of molybdenum and niobium in Chinese steel production strongly correlates with the development of Chinese alloyed steel trade and its transition from a net importer to a net exporter of alloyed steel. While China does not produce niobium and has to purchase the metal on the global market, it has vast resources of molybdenum and thus its trade policy towards this metal does impact the availability of molybdenum and the position of importers[390]. The regional concentration of supply is therefore an important factor in a price framework.

The supply concentration on a corporate level, the level of integration of mining and refining companies in the metal's value chain as well as a company's competitive behavior in the market, i.e. whether it is a commercially passive miner or a strategic marketer with an agenda to actively shape the price furthermore influence the medium and long-term market price level. Specifically, scholars are largely in agreement that oligopolistic structures on the supply side dampen price volatility.[391] In this context, an extreme example is the major producer of niobium, the Brasilian miner Companhia Brasileira de Metalurgia e Mineração (CBMM), who provides close to 90 percent of global niobium and pursued a price setting policy that kept the prices for niobium stable over a period of almost three decades.[392]
However, reliable long-term data on corporate concentration let alone on value chain integration and on corporate conduct are mostly proprietary or not levied at all for refractory metal due to the low profile these metals enjoyed in the past. A perspective on repercussions of the metal price super cycle on the corporate supply level was therefore excluded from the analysis and the focus within this structural force was laid on the far-reaching developments on the national level.

- **Cost structure**
  The cost structure of the marginal producer determines the market price according to economic theory. While interviews with industry experts suggest that price levels often remain above the cost of the marginal producer not only during short periods of price fly ups but also for longer periods of time, the marginal cost position can nonetheless be

[390] Compare chapter 5.1.2, Exhibit 21

[391] Compare also chapter 3.1.3

[392] Compare chapter 6.8.3, Exhibit 65

viewed as a floor price to a given demand.
Factors influencing the cost structure may be numerous. A persistent stabilization of prices at a new price after a prolonged period of strong demand growth indicates that profound changes in the cost structure of the marginal producer took place. This may be a change in the type of the deposit. E.g., in the case of nickel, a switch from nickel sulphide deposits towards more complex nickel laterite deposits is thought to have increased the cost for a ton of nickel by a factor of two between comparable mines. [393]
Specific to selected refractory metals compared to non-ferrous base metals is the mix of supply, which may stem from primary deposits as well as co- and by-production[394]. A change in the significance of either source may cause a shift in the industry and influence the long-term price level.

- **Demand structure**
  According to RADETZKI, unexpected, sustained demand growth is the initiating force of any super-cycle in prices[395]. Having shown that demand for refractory metals does not develop solely according to GDP growth and stage of economic development as suggested by numerous studies on demand for non-ferrous metals, gaining transparency on underlying drivers of demand for refractory metals was therefore a key focus in this work. Findings suggest that while economic development in emerging markets plays an important role, the functional profile of refractory metals has a distinctive influence on the growth prospects of the individual metal. Another influence specific to certain refractory metals emanates from the development of steel production, to which most refractory metals are to some extent tied. Also, it was demonstrated in chapter 6.8 that alloyed steel trade has a significant influence on the regional apparent consumption profile of refractory metals. While alloyed steel trade itself does not affect metal demand aggregated on a global level, it does impact the amount of metal available in a certain form. E.g., the fact that China constrains the direct export of ferro-molybdenum through export restrictions yet exports some of its molybdenum consumption in the form of alloyed steel is irrelevant to the global demand of molybdenum. However, it reduces the amount of ferro-molybdenum available to steel producers outside China. As such, a molybdenum scarcity is induced, which albeit confined to a certain product, may severely impact the price level

[393] Nickel Institute (2007)

[394] Evidence on secondary production, i.e. recycling of metals suggests that it is not cost competitive compared to primary production of non-ferrous base metals. Due to the usually small amounts of alloys used in steel, secondary production is thought to be even less relevant for refractory metals and therefore not listed as a factor influencing price level or volatility

[395] Radetzki (2006), p.63

and volatility.
Finally, direct and indirect substitution effects not confined to either metal group may influence metal demand.

- **Market structure**
The organization of the market place defines the price setting mechanism of a commodity, influences the type and nature of market participants, i.e. whether they are industrial or financial and allows for forward trading of commodities through financial instruments such as futures. Non-ferrous metals are all exchange traded with stock exchanges such as the London Metal Exchange (LME) serving as a central clearing house.
In contrast, price setting mechanisms of refractory metals in the past were based predominantly on producer administered prices or decentralized price negotiations between suppliers and consumers, although this is changing.
The influence of a change in market organization on price volatility is debated in economic literature.[396] In a recent work combining statistical price analysis with underlying industry data, SLADE/THILLE suggest that evidence for an indirect albeit tangible increase of volatility due to exchange trading exists caused by additional market information available to market participants.

The above framework captures the forces shaping the long-term price level and volatility of metal prices that deem relevant from the perspective of the author based on reviewed literature and analyses conducted. Furthermore it depicts characteristics specific to refractory metals. It depends on the individual metal market as well as the observed time period along which forces the long-term price level and volatility is impacted.

In the following chapter the framework laid out in Exhibit 67 is applied to the molybdenum market to illustrate both the practicability of the framework as well as to provide an example of a sustained structural supply side change in a metal market as a consequence of the commodity boom leading to a sustained elevated floor price level.

7.2 Application of the framework to the molybdenum market

Molybdenum's development during the commodity boom has been extraordinary compared to all other metals. Over a period of 7 years, from 2001 to 2008 using three-year rolling averages, the market value of the metal grew by over 53 percent annually[397]. After a short

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[396] Compare chapter 3.1.3

[397] Compare chapter 4.3.1

introduction, the changes in the market structure of molybdenum are discussed along the four dimensions defined in the previous chapter (chapters 7.2.1 to 7.2.3).

Molybdenum has been identified as a high tech alloy, whose concentration in emerging countries is rising but remains below that of advanced economies by an average factor of 3. In advanced economies, the concentration stagnated on average between 1994 and 2008. Prior to the boom molybdenum's price were characterized as low and inelastic. After a short spike in 1980, prices remained at an average real price of 5 US dollars per pound expressed in 2009 prices between 1983 and 2003. But during the 2004 - 2008 boom, prices experienced sustained record levels as high as 41.40 US dollars per pound in June 2005 expressed in 2009 prices. In April 2009, prices plunged before returning to around 12.00 US dollars per pound in December 2009 – a figure almost three times higher than the traditional price level:

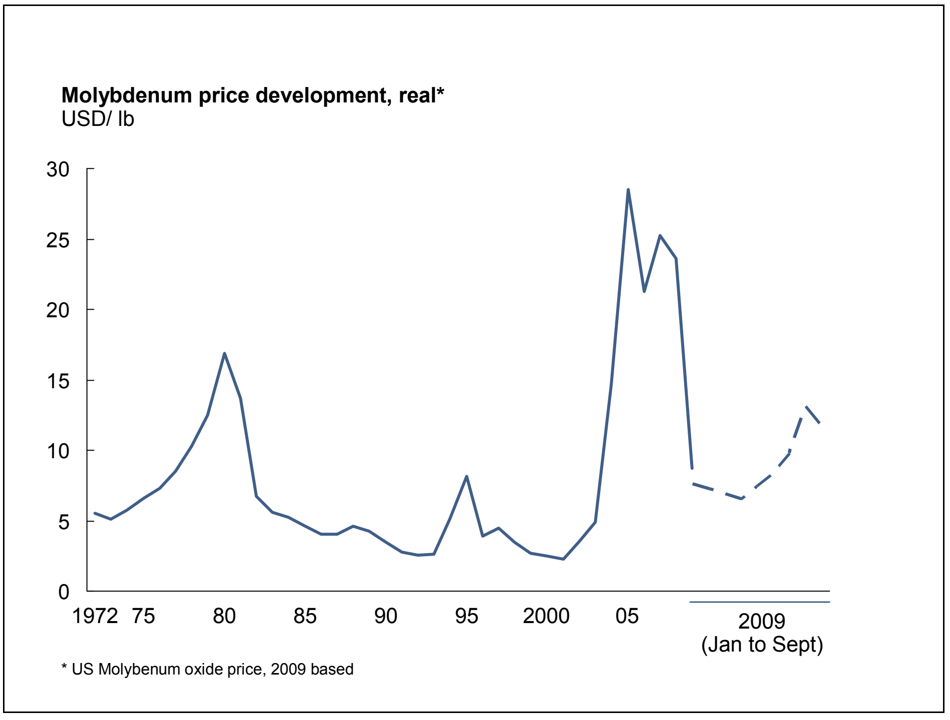

Exhibit 68 – Molybdenum real price development 1972-2009

Source: Own illustration

The molybdenum market experienced structural changes on several dimensions of the integrated framework since the beginning of the commodity boom with a profound impact on the price level of the metal. As will be shown in the following paragraphs, several factors suggest that these changes are there to last.

7.2.1 Industry structure

Molybdenum's industry structure is consolidated on a regional level with the top 5 producing nations comprising over 90 percent of global production in 2008. From 1994 to 2008, the production share of the USA declined as China increased its production:

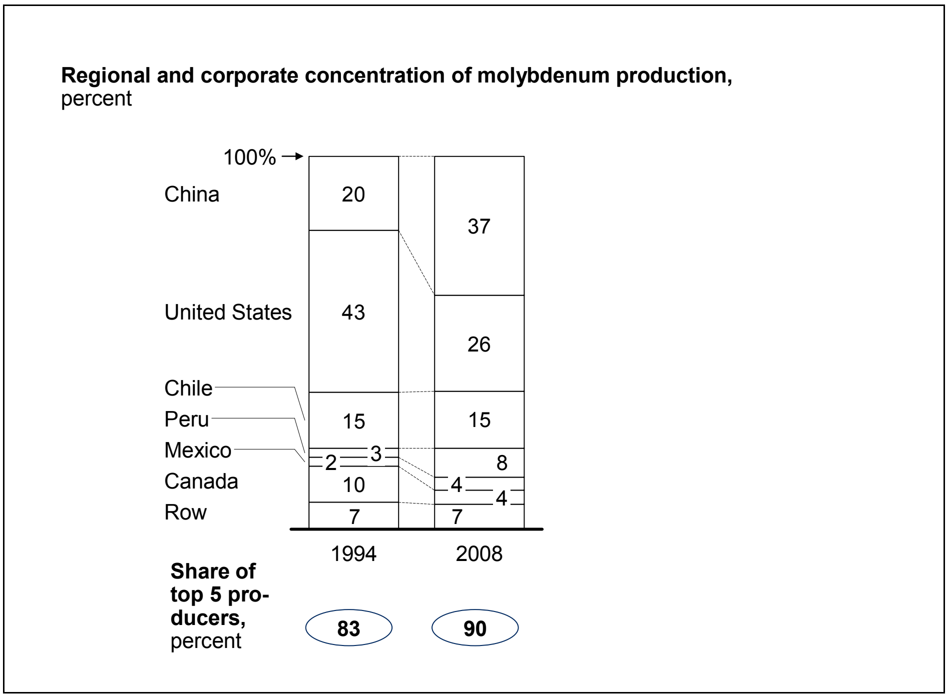

Exhibit 69 – Regional concentration of molybdenum production

Source. Own illustration[398]

China's growing dominance is thought to result from an abundance of molybdenum resources, low cost mining and government tax rebates of exports of refined molybdenum[399].

Prior to the commodity boom, a growing share of Chinese molybdenum exports relative to total global exports reflected China's rising production of molybdenum. Chinese share of global molybdenum exports doubled from 18 percent in 1994 to 36 percent in 2002 measured by estimated weight as importing regions came to rely on molybdenum from China:

398 Production data based on USGS (1996e) and USGS (2010d)

399 Langhammer/ Zeumer (2010), p.17

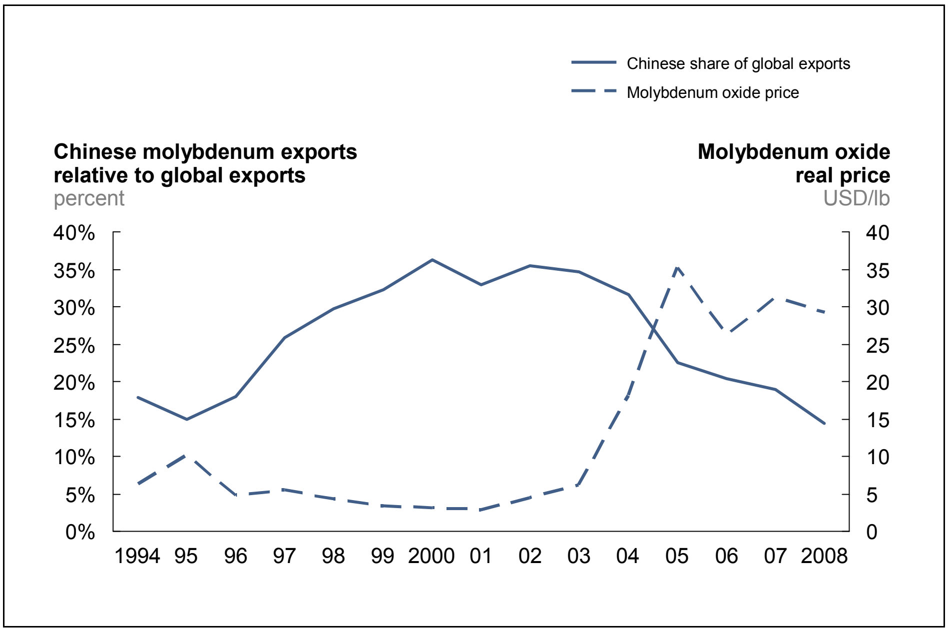

Exhibit 70 – Development of Chinese exports versus molybdenum price development, 1994 to 2008

Source: Own illustration

However, since 2002, China's share of export has fallen drastically to 15 percent in 2008 as depicted by the solid line in Exhibit 70, mainly due to falling exports of ferro-molybdenum as a result of government ordered closure of Chinese ferro-molybdenum producers and molybdenum mines[400]. The sharp drop of exports relative to total exports coincided with a record price rise as global consumers faced a politically induced scarcity. China's fall of exports is a reflection of increased domestic demand as well as a trade policy intended to nourish a downstream steel industry and to increase the share of value adding processing conducted domestically. Since 2005, export tariffs and export quotas have replaced tax rebates on molybdenum exports[401], restricting the export of molybdenum in its intermediate forms. As illustrated in chapter 6.5, Exhibit 46, the rise of molybdenum's concentration in Chinese steel production strongly correlates with rising exports of alloyed steel. Based on this correlation the deduced concentration of molybdenum for domestically consumed steel was calculated to be a maximum of 85 grams of molybdenum per ton of steel. Compared to the calculated concentration of 133 grams in 2008 at a steel production of 500 million metric tons it was estimated that some 24 thousand metric tons of molybdenum may have been exported in the form of alloyed steel in 2008.

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400 USGS (2005f), p.3

401 Compare also Appendix, 9.4

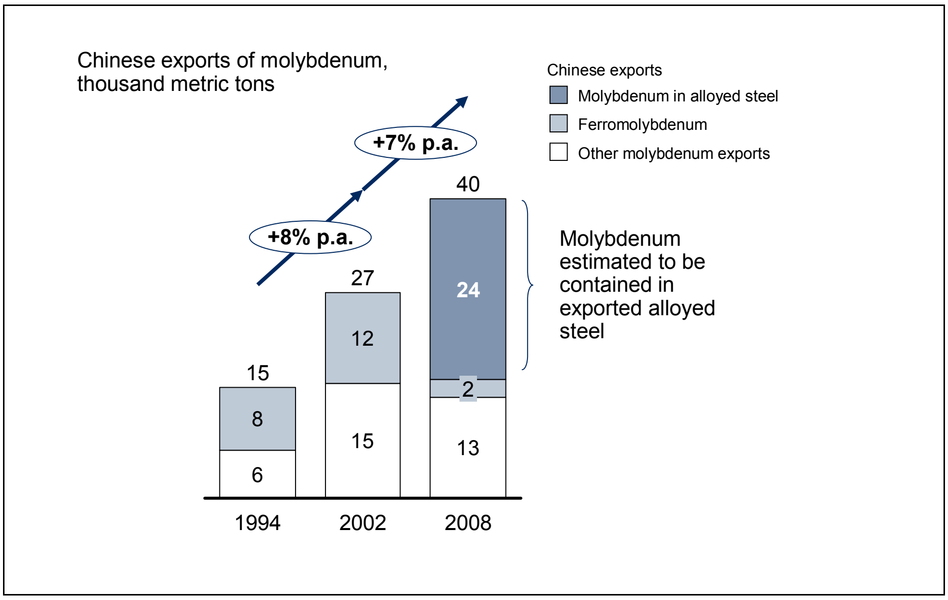

Exhibit 71 – Chinese molybdenum exports, 1994 to 2008

Source: Own illustration

When this amount is taken into account together with estimated Chinese molybdenum exports in intermediate forms in 2008, annualized growth of Chinese molybdenum exports between 2002 and 2008 was 7 percent, only slightly below annual growth of molybdenum exports between 1994 and 2002 as illustrated in Exhibit 71. In effect molybdenum exports from China continued undeterred, albeit ferro-molybdenum was replaced by molybdenum hidden in the higher value-added form of alloyed steel exports.

The drop in exports of molybdenum in its intermediate forms nonetheless had a profound effect on the market as illustrated by the price development. Global industry consumers processing molybdenum such as steel producers faced severe shortages and molybdenum producers outside China rushed to supply the markets:

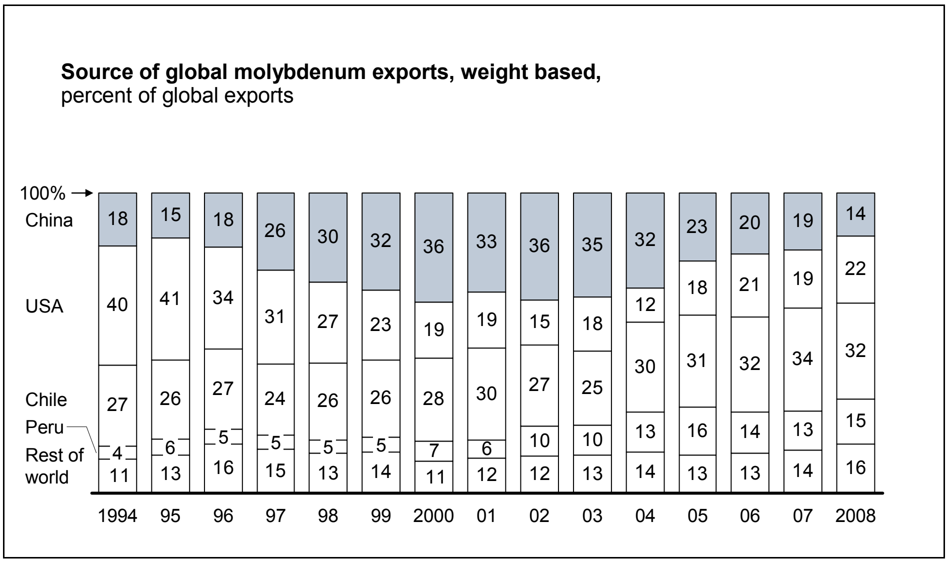

Exhibit 72 – Source of global molybdenum exports, 1994 to 2008

Source: Own illustration

Exhibit 72 illustrates that the drop in molybdenum exports from China after 2002 was mainly compensated by increased exports from the US, Chile, and Peru in 2008. Behind these increases lie new capacity additions, which are structurally different from existing capacity as will be discussed in the next chapter.

7.2.2 Cost structure

Molybdenum stems from two main sources, as a by-product of copper mining and from primary molybdenum sources. For three decades prior to the boom, molybdenum from by-production gradually became the dominant source of molybdenum. While in 1975 molybdenum from copper by-production comprised only 35 percent of total molybdenum production, this share increased to 62 percent by 2006[402]. Two main reasons were responsible for the growing dominance of molybdenum from copper by-production.

- **Favorable cost position**

It is generally less costly to mine molybdenum as a by-product rather than as the primary product as the cost of mining the ore is borne by two metals, not just one. Yet comparing the cost position of by-producers and primary producers directly is difficult as different cost

402 Langhammer/Zeumer (2010), p.16

positions are reported.[403] Nonetheless, reported figures as well as opinions of industry experts indicate that copper by-producers mining molybdenum are in a better cost position compared to peers mining the metal from mines containing mainly molybdenum.

- **Improved molybdenum output per ton of copper**

Copper by-producers steadily improved their output of molybdenum per ton of copper ore mined:

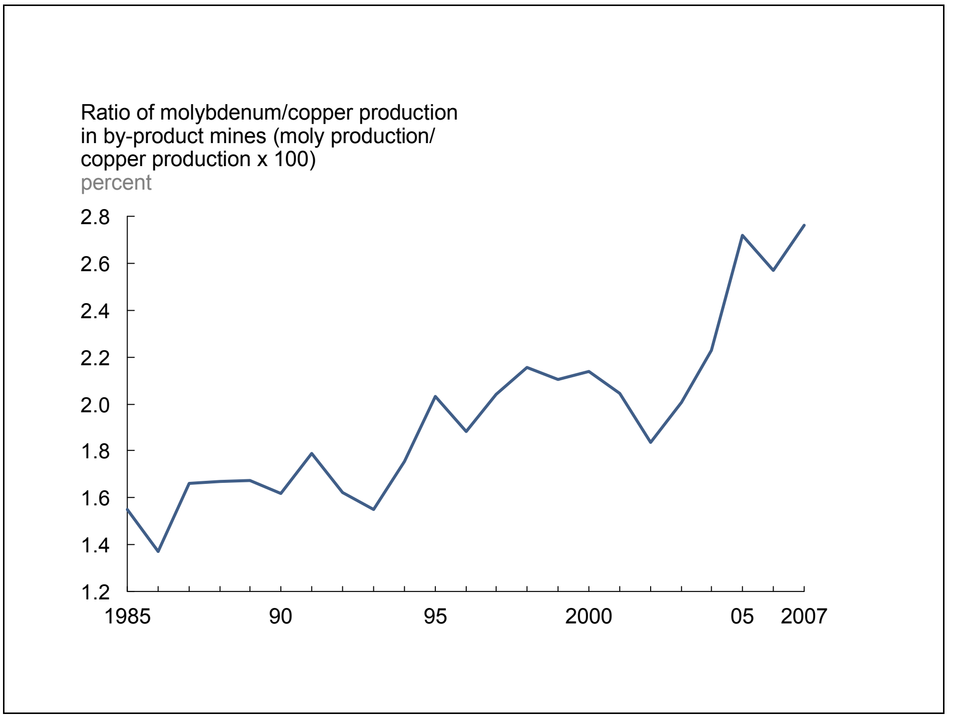

Exhibit 73 – Molybdenum yield from copper by-production, 1985 to 2007

Source: Own illustration[404]

Between 1985 and 2007 the output of molybdenum stemming from copper by-production improved from around 15 kilogram of molybdenum per ton of copper to around 28 kilogram.

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[403] Corporacion Nacional del Cobre de Chile (Codelco), a Chilean copper producer and one of the largest by-producers of molybdenum reported cost of sales of molybdenum to be 2.7 US dollars per pound of molybdenum in 2007. The largest primary mines in North America, the Henderson mine of Freeport-McMoran and the Thompson Creek mine of Thompson Creek Metals Company reported net cash costs of 5.4 US dollar per pound and 7.8 US dollars per pound respectively. The two cost positions are not directly comparable. Cash costs are defined as operating costs including transport, mining, refining, administration costs at the site level and royalties. So-called non-cash expenses such as depreciation and amortization as well as distribution costs and overhead costs are excluded. Cost of sales or cost of goods sold are defined as costs directly attributable to the product sold by a company. See also Langhammer/ Zeumer (2010), p.16; Coldelco (2008), p 162; Freeport-McMoran (2008), p.10; Thompson Creek (2008), p.31f.

[404] Based on data from Raw Material Group (2008)

The result of this development was the gradual closure of primary mines and price erosion between 1980 and 2001 as illustrated in Exhibit 68. However, when the market for molybdenum became undersupplied in 2002 due to a sudden growth in demand and reduced Chinese exports, prices began to rise and by-producers were not able to supply the market sufficiently to balance this scarcity.

Primary producers who had mothballed mines, or had been confined to so-called swing suppliers at marginal cash costs producing opportunistically depending on the price, were unable to bring capacity on line fast enough to satisfy demand.

As molybdenum from by-production does not suffice to meet demand, the majority of announced capacity additions announced to come online between 2007 and 2015 are primary mines:

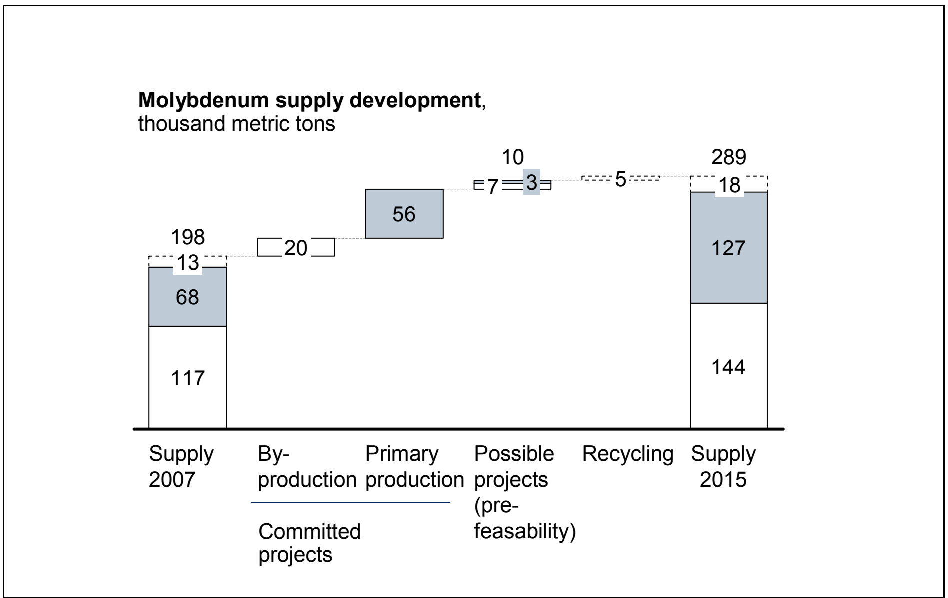

Exhibit 74 – Molybdenum supply development forecast, 2007 to 2015

Source: Langhammer/ Zeumer (2010)

The supply of molybdenum is forecasted to increase to 289 thousand metric tons in 2015 from 198 thousand metric tons in 2007. Of this, 65 percent are reported to be primary molybdenum projects. The additions of primary molybdenum capacity lift primary producers from irrelevance. Based on the supply forecast in Exhibit 74, the share of primary producers increases to 44 percent in 2015 from 38 percent in 2007.

This development brings about a structural change to the molybdenum cost curve as it alters the cost position of the marginal producer noticeably. New primary capacity is added at full cost, i.e. carries cost of financing the capacity. Furthermore, operating costs of new primary mines are significantly higher than of established primary mines and range between 11 to 14.5 US dollars per pound according to one industry report[405] compared to the aforementioned 5.4 US dollars per pound for the Henderson mine and 7.8 US per pound for the Thompson Creek mine.

Whether this new capacity is needed, which mine will ultimately be in the position of the marginal producer and therefore which cost position will determine the future floor price of molybdenum depends on how demand will develop going forward.

7.2.3 Demand and market structure

Molybdenum apparent consumption was relatively flat prior to the commodity boom between 1994 and 2002 but experienced a boost between 2002 and 2008:

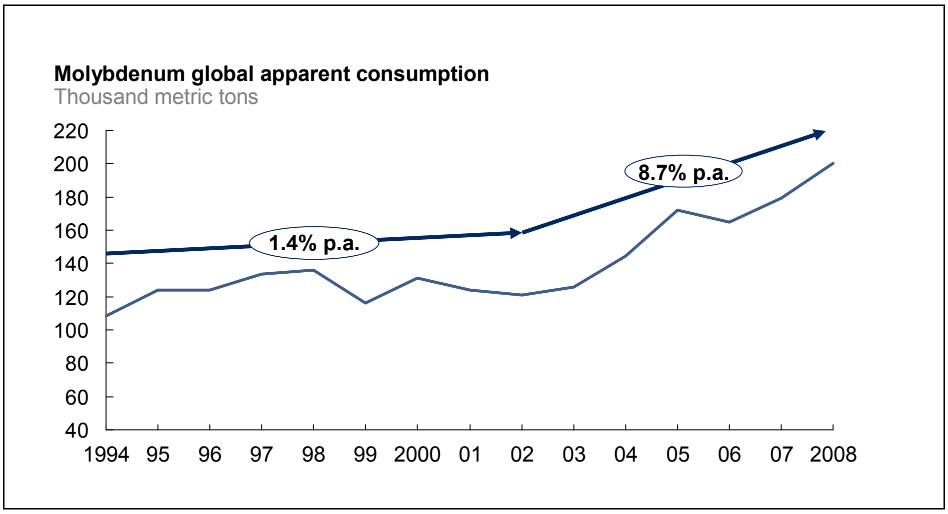

Exhibit 75 – Molybdenum apparent consumption, 1994 to 2008

Source: Own illustration

The underlying drivers for molybdenum demand originate in several long-term trends spurring demand for the functions molybdenum entails in steel, which were found to be enhanced corrosion resistance in combination with chromium in stainless steel, high strength and temperature resistant steel grades.[406] Demand for molybdenum therefore depends on the sustainability of these trends:

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405 Langhammer/Zeumer (2010), p.20

406 Compare chapter 6.1, Exhibit 32

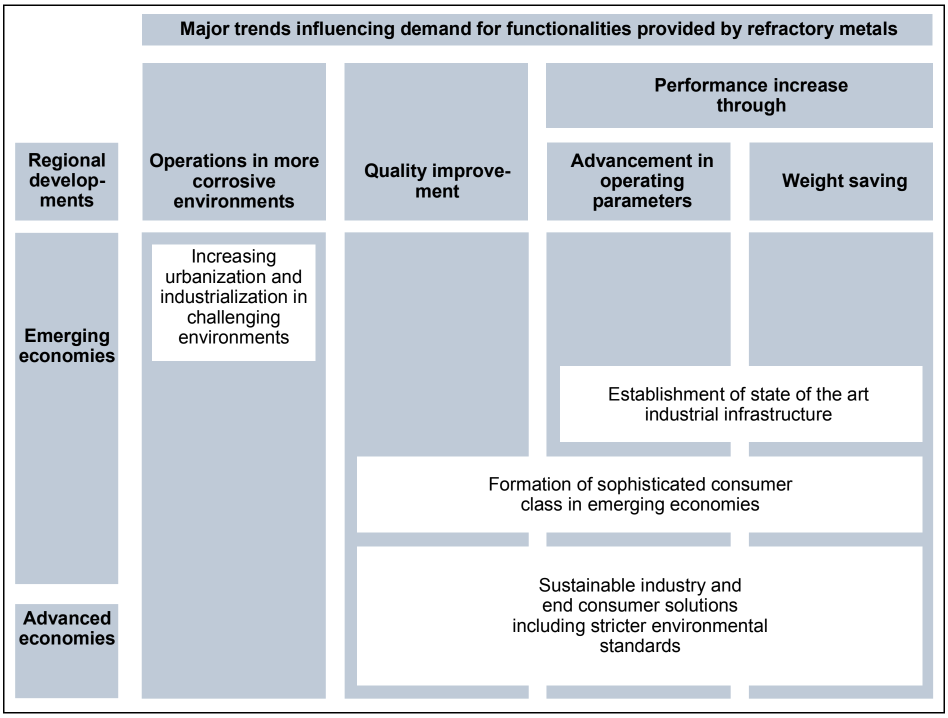

Exhibit 76 – Long-term trends and regional developments

Source: Own illustration

Most of these trends are originating in emerging economies. Foremost the establishment of a modern industrial infrastructure in emerging economies, notably China and India to be able to handle advanced operating parameter can expected to be a major driver of molybdenum demand. In operations in more corrosive environments, molybdenum furthermore profits from its catalytic properties, used to desulphurize sour oil. Molybdenum also benefits from the substitution of nickel containing austenitic stainless steel for ferritic stainless steel as it replaces nickel's properties such as enhanced corrosion resistance in ferritic stainless steel. This type of stainless steel is enjoying an increasing popularity in China and to a lesser extent in India.[407]

Due to its role as an industrial metal, demand for molybdenum will to a lesser degree stem from consumer based trends, which comprise the formation of a sophisticated consumer class in emerging economies as well as sustainable end consumer solutions.

While the molybdenum market as all other commodity markets is reported to have experienced a major contraction of demand during the economic crisis visible in the dramatic

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[407] Nickel Institute (2007)

price drop at the end of 2008, the above described trends are of long-term nature and are expected to weather the crisis largely undeterred[408].

A specific metal demand forecast is subject to a number of qualified assumptions beyond the scope of a scientific work. To build a demand model based on the growth decomposition approach applied in this work with demand global $D_{i,t=T}$ for metal i for a point in time T for all n countries equals

$$
\begin{aligned}
& D_{i,t=T} \\
& = \sum_{k=1}^{n} D_{ik,t=T} \\
& = \sum_{k=1}^{n} \left[GDP_{k,t=1}(1+s_k)^T \cdot PCI_{k,t=1}(1+w_k)^T \cdot MCP_{ik,t=1}(1+x_{ik})^T \right]
\end{aligned}
$$

a number of country specific or global forecasts are necessary as input factors, such as the growth rates of GDP, of steel production and of material composition of product (MCP), i.e. a prognosis of the concentration development of molybdenum in steel. As illustrated in the analysis of metal market in chapters 6.8.1, 6.8.2, and 6.8.3, specific factors influencing the demand of individual metals may as well be applied to refine the forecast on a disaggregated level. Some of these input factors are proprietary or rely on specific industry knowhow.

One scenario based forecast estimates global growth rates of molybdenum from 2007 to 2020 between 2.6 percent in the worst case scenario and 4 percent in the best case scenario.[409] Combining these growth rates with the structural supply side change towards a larger share of molybdenum from primary molybdenum sources in 2015 yields a new floor price level of 10 to 14 US dollars per pound of molybdenum[410], significantly above the long-term average of 5 US dollars per pound. As an indication that this is indeed happening, molybdenum prices appear to stabilize at the upper value of this range in 2010.

In addition to a structural change on the supply side, a fundamental change in the organizational structure of the molybdenum market is happening as well.

Until recently, suppliers, traders and consumers of molybdenum as well as of other refractory metals conducted metal trading decentralized with reference prices being published weekly, monthly or quarterly in respective trade journals.

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[408] Langhammer/ Zeumer (2010), p.18

[409] Langhammer/ Zeumer (2010), p.18f.

[410] Langhammer/ Zeumer (2010), p.20

Since February 2010, molybdenum is one of two refractory metals that are traded at the London Metal Exchange in recognition of an increasing need for a centralized trading place of refractory metals to allow participants to hedge price volatility.

This step underlines the growing significance of molybdenum as decisive factor influencing the cost, risk, revenue, and profit position of market participants. It also brings about two main consequences to price volatility. Recent scientific evidence suggests that prices of metals traded at exchanges are subject to higher volatility due to an improved flow of information[411], such as a better reflection of future scarcity. Furthermore, exchange trading opens the door to financial investors willing to invest directly into the commodity. One the one hand this should be welcomed as such investors offer offsetting positions to industry market participants longing to hedge their exposure to price volatility. On the other hand, if supply constraints in the molybdenum market as observed between 2002 and 2008 reoccur in the future, commodity speculators will find it easier to influence the market price in the short term as observed for non-ferrous metals during the commodity boom.

[411] Slade/ Thille (2006), p.251

8. Discussions and conclusions

The purpose of this chapter is to discuss the conclusions of this work. As a first step, conclusions are summarized along the research questions posed in chapter 3.4 (chapter 8.1). Secondly, implications for scientific research are deduced in chapter 8.2. In chapter 8.3 implications for corporate practitioners are discussed.

8.1 Summary relating to research questions

At the beginning of this work on the basis of the reviewed literature, four research questions were posed. Along these questions, the results of this work are now summarized.

Research question 1: What are distinguishing elements of non-ferrous base metal markets and refractory metal markets that justify a separate examination of the latter?

It was found that refractory markets are distinctive from non-ferrous metal markets in several aspects.
On the supply side, the global production of refractory metals is on average more concentrated than that of non-ferrous base metals. When global export concentration is compared, the higher concentration level of refractory metals is even more striking. Specifically, China's role as a heavy weight on the producing and exporting side as well as on the consuming side of many refractory metals in combination with export restricting trade policies is the cause of more pronounced market imbalances in the refractory metal markets. The impact of trade restrictions is therefore highly visible to the consumer. Furthermore, a relevant share of production stems from by- and co-production in selected metal markets and makes these markets more vulnerable to over- or undersupply as production volume is not directly linked to demand but to the production of the main product.

On the demand side the analysis of apparent consumption of refractory metal demand relative to economic growth yielded striking differences to non-ferrous base metals. For the latter, the ratios of apparent consumption and economic growth developed along patterns of stage of economic development and fell almost unanimously in advanced economies, while rising in emerging economies during the observed time period as predicted by economic theory. For refractory metals, no such obvious pattern could be observed. The ratios of apparent consumption and economic growth developed along patterns specific to metal and economy. The orientation of the ratio alone did not allow an inference of the stage of economic development.

Finally, the market organization of refractory metal markets is different from non-ferrous base metals. Spot market trade in the latter markets is conducted on central stock exchanges, introducing market participants to forward trading. Such central spot market trade did not exist for refractory metals but was accomplished in a decentralized form until February 2010, when for the first time two refractory metals, molybdenum and cobalt were admitted to stock exchange trading.

Research question 2: How does the distinct demand structure of refractory metals influence the demand development of such metals?

The question was answered for five refractory metals used predominantly as alloys in steel. It was deduced that the functional profile of a refractory metal, i.e. the functions it effectuates in steel has a pronounced influence on the demand development of the individual metal. Refractory metals are used in often miniscule amounts as alloys in steel. As such, their cost share in the end application is small. Yet the functions refractory metals bring to bear in the steel grades used are indispensable for the end application. Three main functions relevant to the end application, namely corrosion resistance, strength and high temperature strength were identified. It is the demand for these specific functions, which was found to significantly influence the demand development for refractory metals. It was furthermore shown that four long-term industry and consumer trends are influencing this functional demand. Weight saving and advancement of operating parameters to increase performance are not new trends, but an increasing awareness for climate change and sustainability accelerates the development for lighter more enduring steel grades to function more efficiently. Relentless quality improvement as a further trend is demanded not only by affluent consumers in advanced economies but by a rising class of influential and sophisticated consumers in emerging economies. Finally, operations in more corrosive environments were identified as a fourth trend, e.g. constructions in demanding environments like the Gulf region or in more polluted areas in emerging economies.

Research question 3: How can the impact of influences related to the demand structure of refractory metals be quantified and which other factors influence refractory metal demand?

The question was answered for four refractory metals. To measure the impact of a refractory metal's functional demand profile, apparent consumption was estimated for 34 economies for the period prior to the commodity boom from 1994 to 2002 and from 2002 to 2008. The economies were clustered not only according to stage of economic development but also by steel production output, yielding altogether 7 clusters.

Growth in apparent consumption by cluster was then decomposed into growth in line with GDP growth, growth in line with product composition of income (PCI), i.e. growth of steel production relative to GDP, and growth of material composition of product (MCP), i.e. growth of the concentration of the refractory metal per metric ton of steel production. The variable MCP as the only metal dependent variable was used to measure how the demand development of a metal reflects the metal's individual functional profile as well as to assess regional consumption differences.

Of the four examined metals, manganese and chromium could be classified as universal alloys enjoying a wide spread use globally visible in marginal differences between the MCP levels of advanced and emerging economies. Yet differences between the two metals exist, which can be traced back to the different functions chromium and manganese effectuate in steel. An increase in the concentration of chromium per ton of produced steel was responsible for a larger share of growth of apparent consumption than for manganese. Chromium has a unique role as the main corrosion inhibitor and is the key element in stainless steel. Through its corrosion inhibiting function it is directly profiting from corresponding trends demand more corrosion resistant material. Furthermore, while most clusters containing emerging economies reached or surpassed the concentration level of the US by 2008, a gap towards other advanced economies remained, which could in part be explained by cultural differences in the US regarding the preference of aluminum over stainless steel. Manganese is mainly used for oxide and sulfur fixing in steel as well as an alloy to refined the grain structure in steel, effectuating an increase in strength and toughness. As such, it is widely used in most alloyed steel grades but beyond that does not benefit visibly from any of the identified trends. Its consumption relative to steel was shown to have fallen on average due efficiency improvements in steel production.

Molybdenum and niobium were classified as advanced alloys because their MCP level in advanced economies was estimated to be higher than in major emerging economies by a factor of three. This indicates that the share of demand for steel containing these alloys relative to total steel demand is much higher in advanced than in emerging economies. Differences in the development of both metals based on differences in their functions they effectuate in steel existed here too visible in the different growth rates.

Growth in the MCP level of niobium contributed a large share to apparent consumption growth in advanced as well as in emerging economies whereas molybdenum's MCP rate was largely stagnant in advanced economies and grew only in emerging economies. This can be related to niobium's unique function of increasing the strength of steel and thus allowing the development of light-weight steel grades, catering directly to the trend for lighter yet high-strength materials in the automotive industry. Molybdenum, while also used as a steel strengthening alloy, benefits from this in combination with its corrosion inhibiting and high temperature resistant functions it effectuates in steel and stainless steel. As such, it is found mostly in industrial applications, compared to niobium, of which a major share is used in the improvement of end consumer products like automobiles. The growth rates of their different end use market are reflected in the growth of apparent consumption of molybdenum and niobium.

Furthermore, factors influencing individual metals markets beyond the general trends identified in research question 2 were analyzed. It was found that chromium, molybdenum, and niobium benefit additionally from substitution dynamics. Chromium profits from substitution trends of carbon steel for stainless steel. Molybdenum benefits from a shift within the stainless steel industry away from nickel containing austenitic steel to ferritic stainless steel, in which molybdenum replaces nickel related properties. Niobium benefits from the substitution of vanadium, especially in pipeline steel and in steel grades used in the automotive industry.

Beyond this classification, alloyed steel trade by country cluster was examined to assess the effect of alloys contained in such form of trade on the average MCP levels and therefore on the demand for refractory metals.

It was demonstrated that alloyed steel trade has a significant impact on the MCP levels of certain clusters. The cluster with the highest MCP levels for most metals was also the largest net exporter of alloyed steel, measured relative to domestic steel production, whereas the cluster with the lowest MCP rates for most metals was also the largest net importer, measured relative to domestic steel production.

Finally, a significant structural change in the global export market of alloyed steel initiated by China was visualized. The cluster including China switched from being a large net importer to a balanced trade of alloyed steel measured by value and to a significant net exporter measured by weight between 1994 and 2008. China's MCP growth for molybdenum and niobium strongly correlated with its rising net exports of alloyed steel between 2000 and 2008, suggesting that part of China's demand for these metals is re-exported in the form of alloyed steel.
The increase in the Chinese's share of global alloyed steel exports had a significantly negative impact on the share of Japanese exports measured by value and to a lesser extent on the weight share of major European steel producers. Specialized European steel producers were able to maintain their share of global exports both measured by value and by weight.

Research question 4: What are the structural forces in a metal market that impact the long-term level and volatility of a metal price and which characteristics within these forces are specific to refractory metal markets?

Four structural forces were identified to capture the relevant influences on price level and volatility of metal markets: industry structure, cost structure, demand structure and market structure.

Industry structure comprises regional concentration of production, trade and level of government intervention in trade as well as corporate concentration including also value chain integration and corporate behavior[412]. Specific to refractory metals are a higher average level of regional concentration and correspondingly a higher concentration in trade and a stronger exposure of regions relying on imports to export restricting measures. Cost structure describes the cost composition of existing and new capacity and corresponding changes resulting from deposit type changes, source type changes, government regulation or relevant long-term changes in specific cost levers. Specific to refractory metals is that production may stem from primary as well as by-or co-production sources. A structural shift within these sources may have a significant influence on the cost position of the marginal producer and may alter the long-term price level. This was quantified for the example of molybdenum. Demand structure captures influences on the demand side of the metal, which ultimately determines the marginal producer and therefore the floor price level. Also, demand fluctuation may influence price volatility. Demand structure comprises economic development of consuming regions, substitution as well as government regulation. Specific to refractory metal demand is the influence of the functions a metal effectuates in steel on the demand for this metal. A metal's individual functional profile entails a demand for these functions, which was demonstrated to originate in major industry and consumer trends. The small share of cost relative to the total cost of the end product is furthermore specific to refractory metals, causing substitution trends affecting refractory metals to originate from the substitution of a steel or stainless steel grade rather than from the desire to replace the metal itself. The substitution of austenitic stainless steel for ferritic stainless steel is a good example illustrating the indirect role of refractory metals and the direct role of nickel as a non-ferrous base metal. The substitution trend originated in the aspiration of producers to substitute for nickel for its significant influence on the level and volatility of stainless steel prices[413], emphasizing the direct effect of the cost position of nickel. Molybdenum was used to replace nickel-related functions in ferritic

[412] The corporate concentration level was not compared between non-ferrous base and refractory metal markets due to lack of reliable long-term data.

[413] ISSF (2007), p.1f.

stainless steel, so benefited from the substitution indirectly through the functions it effectuates in stainless steel.

Market structure summarizes factors influencing price level and volatility resulting from the market organization. The latter defines the price setting mechanism and the type of market participants active in the market. Non-ferrous base metal markets have centralized spot markets and therefore a centralized price setting process with daily reference prices available to market participants at a stock exchange. The exchange based trading also allows forward trading and introduces financial investors to metal trading. Research indicates that the improved flow of information in exchange traded commodities increases price volatility[414] and that short-term volatility may result from price speculations[415]. The price setting mechanism in refractory metal markets was in the past based on decentralized trading between suppliers, traders and consumers and reference prices from interviews with market participants were published in trade journals. Financial investors had no direct access to the market other than to invest in listed stocks of companies active in the molybdenum industry or by purchasing physical volumes. Hedging against price volatility through forward trading was not possible. The introduction of the trading of molybdenum and cobalt futures at the London Metal Exchange in February 2010 fundamentally changed the market organization of two refractory metals with corresponding consequences on price volatility.

8.2 Implications for further research

In the following chapter, implications for research are discussed from a content and methodological perspective (chapter 8.2.1). In chapter 8.2.2, restrictions in this work are critically discussed and topics for further research are suggested.

8.2.1 Content and methodology based implications

The motivation for this work was based on two observations in the discussion about the economic development of metal markets. Firstly, it was noted that mineral economists are in disagreement how to evaluate the recent commodity boom with respect to its long-term impact on metal prices. Secondly, the absence of an adequate analysis of refractory metal markets matching the depth and level of quantification found in works on non-ferrous base

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[414] Slade/Thille (2006), p.251

[415] Brunetti/Gilbertz(1995), p.237

metals implied that any conclusions on economic dynamics of metal markets were of limited validity as refractory metals were excluded a priori.

The work on hand contributes to the discussion on the long-term impact of the commodity boom on metal prices. Based on industry insights and on the review of existing literature on the topic a framework was deduced that illustrates through which forces structural changes in metal markets may occur and how this may impact level and volatility of metal prices. In a case study on the molybdenum market, the occurrence of structural changes and the measurable impact on prices were demonstrated.

This approach enriches the discussion on structural changes in metal markets and long-term changes in metal price levels in three ways. The four forces framework laid out in Exhibit 67 provides a holistic approach to structure future discussions along the dimensions that have a relevant impact on long-term metal prices and volatility. Furthermore, it expands the discussion beyond the future cost structure of the marginal producer and explicitly revives the dimension of national concentration, which was long dismissed as irrelevant in times of globalized trade. Also, the integration of insights from the analysis of refractory metal markets emphasizes the framework's applicability to this particular group of metals and at the same time yields important differentiating factors within the structural forces between non-ferrous base and refractory metal markets. Developments in refractory metal markets provide important examples for the topicality of the debate, e.g., changes in the dimension market structure. Finally, the example of molybdenum illustrates the occurrences of structural changes in a metal market along several forces as a consequence of the boom and provides a quantitative estimation of the long-term price impact.

The focus of this work on refractory metal markets expands the scope of mineral economics towards metal markets, which are to date underrepresented in literature, yet whose rising economic relevance is emphasized by extraordinary strong growth in market value and demand beyond that of non-ferrous metal markets and which will continue to gain weight in the future.

The differentiation from non-ferrous base metals based on major differences on the supply and demand side underlines the particularities of refractory metal markets and emphasizes the necessity for a distinctive perspective and exclusive treatment of the markets. Structural differences on the demand side between non-ferrous base and refractory metals were addressed by an in depth analysis of refractory metal demand. It was demonstrated that refractory metal demand patterns are significantly influenced by the individual functional profile of each metal. This influence was traced back to underlying industry and consumer trends and quantified by analyzing the concentration development of each refractory metal in steel by country cluster.

It was shown that depending on their functional profile refractory metal concentration in steel is either measurably influenced by a country cluster's stage of economic development or enjoys a wide spread use regardless of macroeconomic differences. Furthermore, the functional profile of refractory metals has a visible influence on growth of apparent consumption. The concept of a refractory's metal functional profile and the link to overarching industry and consumer trends may therefore be understood a helpful toolkit to assess and comprehend the demand profile and demand development of a refractory and possibly also of other minor metals going forward.

In addition, incremental regional and national differences in advanced economies regarding the degree of specialization in steel production towards high end steel grades were identified and the impact of net alloyed steel trade on the average concentration level of a country cluster illustrated. Finally, the advantage of domestic assets of refractory metals was illustrated in the case of molybdenum in China. The restrictions of molybdenum exports in its intermediate forms could be linked to China's development towards a leading net exporter of alloyed steel at the expense of net importers of molybdenum, which demonstrates that the topic of resource availability and security is of imminent relevance to metal markets and should not be dismissed by scholars.

From a methodological viewpoint, price was chosen as the ultimate sensor to reflect relevant structural changes in metal markets. In differentiation towards existing research, metal prices were not examined based on the statistical analysis of price charts. Rather, structural changes in metal prices were attributed to either force within the four forces framework laid out in Exhibit 67, chapter 7.1.

This approach complements existing metal price research of statistically identified super cycles with a long-demanded perspective on the metal industry based roots of super cycles by unifying industry insights in an integrated framework to establish a holistic approach to price analysis in contrast to studies that observe and analyze structural changes in a metal industry but fall short of relating these back to a price impact.

The approach chosen in this work owed to the author's practical industry background and intentionally leaned more towards the integration of solid industry knowledge than pure statistical rigor. The insights gained are nonetheless meant to contribute to prospective studies by scholars from various backgrounds and to the lively debate about the future development of metal prices.

8.2.2 Critical assessment of restrictions and suggestions for further research

The conclusions based on this work are subject to several restrictions that may be classified as restrictions with respect to data, methodology and scope.

From the viewpoint of data sources employed, the choice of refractory metals as the core markets for demand analysis entailed significant limitations. Officially reported consumption data are published only for non-ferrous base metals. Consequently, apparent consumption was approximated based on production and import and export data of refractory metals in their intermediate forms. The amount of refractory metals contained in annual import and exports flows was estimated based on fixed content assumptions as well as variable content calculated based on reported trade value and metal price.[416] Despite plausibility checks and exemption of metals from the analysis that were found to yield implausible results, namely cobalt and vanadium, results were not unilaterally satisfying. Often, mirror reports had to be used for discrete periods as trade figures from the original reporter could not be reconciled. However, the choice, which figures to use as well as which methodology to choose to calculate metal content is subject to qualified assumptions and cannot be justified by hard facts. Furthermore, no adjustments were made for stock inflows and outflows due to lack of data. Finally, major producers of a certain metal, e.g., South Africa for chromium, Brazil for niobium, and Chile for molybdenum had estimated consumption rates significantly higher than could be explained by either domestic demand or the export of alloyed steel. This suggests that either significant discrete exports flows containing refractory metals were not captured or that metal content in accounted export flows was underestimated.

Methodologically, the choice of the intensity of use technique to decompose growth of apparent consumption was substantiated based on the top down approach to decompose growth in apparent consumption[417]. However, only material composition of product was further examined as the variable directly dependent on metal apparent consumption. It is implicitly conjectured that GDP growth and steel growth are linked to refractory metal demand growth but a formal proof was omitted. A formal analysis linking GDP growth and growth of steel production relative to GDP to growth of refractory metal demand would further solidify the explanatory value of this approach. Furthermore, the clustering concept applied to aggregate the analyzed economies is subject to qualifications. The dimension capturing steel production is based on the absolute production volume. No correction was

[416] Compare chapter 4.2

[417] Compare chapter 4.1.1

made to adjust for scale effects between countries, nor can the author claim that concentration levels and apparent consumption of clustered countries develop in lock-step within each cluster. Whereas differences in concentration levels between clustered countries were highlighted and in some cases traced back to country specific singularities, immense scale effects particularly in cluster 1 are apparent. China's production volume dwarfs that of India and Russia yet the three countries are bundled together. While a simple adjustment, namely mapping steel production per unit of GDP instead of absolute steel production does not remove the gap between China and its peers, other ways to account for the influence of steel production are thinkable such as mapping steel production by population. Treating China as a separate entity is also justifiable based on the unique status of this economy.

The focus of the work on refractory metals used predominantly as alloying elements in steel limits the scope of this work. Other refractory metals, namely cobalt, titanium and tungsten were exempted. Conclusions with regards to the significant influence of the functional demand profile and the link to major industry trends are therefore based on a subset of refractory metals and their validity in other markets is subject to verification.

For future research the following recommendations may be deduced. With respect to the situation of apparent consumption data, trade figures are likely to remain the raw data source of choice due to lack of officially published figures, which would in any case be subject to similar constraints. However, estimates can be refined and the reliability improved by increasing the granularity of trade flow data beyond the six-digit limitation imposed on data published by UN Comtrade. More granular data are available directly from the reporting countries. This of course entails a much more tedious process of data collecting and data mining and most likely limits the analysis to a few reliable reporting countries. However, within the country clustering concept developed in this work, calculating refined apparent consumption for one representative economy by cluster would improve the validity of results.

Furthermore, the analysis of chromium, manganese, molybdenum, and niobium and to a limited extent of vanadium can only be a first step of shedding light on the group of refractory metal markets. As the above mentioned are furthermore a special subset within refractory metals, an in-depth analysis of the growth drivers of cobalt, titanium and magnesium as well as the examination of sustained structural changes during the commodity boom along the four-forces framework can be expected to yield further insights into this group of metals. Also, the group of other minor metals contains highly innovative materials, whose markets are subject to volatile demand and a concentrated supply structure. Approaching these metals through the functional approach suggested in this work could facilitate a thorough understanding of the dynamics of these markets essential to market participants.

Finally, the period analyzed reaches till 2008 as data beyond this year were not yet published during the time of writing. Given the drastic fall in prices and demand across global commodity market starting mid 2008 and the subsequent contraction of global GDP growth due to the by some accounts still enduring economic crisis in 2010, the analyzed time period does not capture the full impact of the crisis. Applying the developed framework to metal markets during the crisis and beyond would help to refine factors identified within the structural forces and test the solidity of the framework. An extension of the time period beyond 2008 would also aide to verify the robustness of the identified trends affecting metal demand through a metal's individual functional profile.

8.3 Implications for practitioners

The extraordinary development of refractory metals during the commodity boom lifted selected smaller-scale metals from their limited significance up to eye level with non-ferrous base metals. Overall, refractory metals are becoming increasingly important to market participants with respect to cost, risk, revenue and profit.[418] The introduction of cobalt and molybdenum future trading at the LME is a visible consequence of this development and a reaction to a growing urgency of market participants to hedge their exposure to these markets as well as to calls from financial markets for better access to lucrative investment opportunities.

While the economic crisis has jeopardized numerous investments in capacity expansions as suppliers face liquidity shortages and are seeking ways to reduce capital expenditure and operating costs to generate cash, it was demonstrated that the demand for the examined refractory metal markets is tied to industry and consumer trends that are expected to remain valid and secure solid demand growth going forward. It is therefore assumed that refractory metals are losing none of their relevance gained during the commodity boom in the economic crisis.

Suppliers should recognize the growing share of revenue and profit stemming from refractory metal markets and reevaluate the significance of these metals in their portfolio, in particular the classification of by- or co-product relative to a main product as well as their market approach.

For consumers, selected refractory metals are becoming a cost and a risk factor of hitherto unknown relevance. Steel producers as the major consumers of the metals examined should

[418] Langhammer/ Zeumer (2010), p.21

reconsider their supply strategy. A sole reliance on spot market supply may not suffice in the future and reports exists of top steel producers seeking long-term sourcing contracts to mitigate the risk of supply constraints in refractory metals.[419]

The exchange trading of cobalt and molybdenum offers new opportunities but also carries risks for industrial market participants. The possibility for market participants to hedge their exposure to price volatility allows to mitigate the risk of fluctuating costs and revenue. On the other hand, in times of tight supply, commodity speculators now have easier access to these markets to magnify the short-term price impact of a perceived scarcity.

China's role in selected refractory metal markets deserves special mention. Its unmatched need for raw materials to sustain its economic growth has made it the center of metal demand growth globally. However, its role on the supply side is of equal significance. As a resource rich economy, it has vast domestic assets in many refractory metals and has assumed the position of a dominant consumer as well as a major global supplier. That makes it fundamentally different from other resource rich emerging economies, which do not have a large domestic market and are relying on exports of raw materials to receive foreign exchange. China's determination to pursue domestic interests over unobstructed trade takes shape in the form of export rebates having become export restrictions. The effect on Chinese metal exports is considerable. It was illustrated that China's position in the alloyed steel market changed fundamentally from being a net importer to becoming a net exporter, a development that strongly correlates with a rising concentration of molybdenum and niobium in steel production. In parallel, these increased alloyed steel exports replace exports of metals in their intermediate forms as illustrated for the molybdenum market.[420] In consequence, China subsidizes a domestic down stream industry relying on refractory metal supply and nourishes overcapacities. This constellation has severe implications for steel producers outside China. Their position is doubly inferior to their Chinese counterparts. Access to raw materials is restricted and the competitiveness of their products outside domestic markets, which are often protected by import tariffs, is jeopardized. At the same time, Chinese overcapacities in alloyed steel are pushed onto the global market.

The analysis of the alloyed steel export market bears witness to signs how this development measurably affects steel producers outside China. Since 1994, the share of net alloyed steel exports of global alloyed steel exports of major Western European economies dropped from around 9 percent to below 4 percent measured by weight and to just above 5 percent measured

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419 See Langhammer/ Zeumer (2010), p.21 for an example of the molybdenum market

420 Compare chapters 6.8 and 7.2

by value. For Japanese exports, the fall in market share is equally severe. Here, net exports relative to global exports fell from over 11 percent to 8 percent measured by weight and below 6 percent measured by value. While this is not to say that absolute exports of alloyed steel of either major Western European steel producers or Japan have fallen, neither region participates in the growing export market for alloyed steel. On the contrary, both large Western European and Japanese steel producers are marginalized on the global market.

Yet the export share development of European economies with a smaller-scale steel production such as Sweden, Finland, and Austria also highlights a path to successfully maintain a competitive edge globally going forward. Home to innovative steel producers that specialize in high end steel grades visible in high concentration levels of refractory metals per unit output of domestic steel production, these countries have on average maintained an unperturbed share of global alloyed steel exports.

9. Appendix

9.1 HS codes trade data

Chromium (HS 1992)		Manganese (HS 1992)		Molybdenum (HS 1992)	
HS code	**Description**	**HS code**	**Description**	**HS code**	**Description**
2610	Chromium ores and concentrates	2602	Manganese ores, concentrates, iron ores >20% Manganese	261310	Molybdenum concentrates, roasted
2819	Chromium oxides, hydroxides	2820	Manganese oxides	261390	Molybdenum ores and concentrates except roasted
720241	Ferro-chromium, >4% carbon	720211	Ferro-manganese, >2% carbon	720270	Ferro-molybdenum
720249	Ferro-chromium, <4% carbon	720219	Ferro-manganese, <2% carbon	8102	Molybdenum and articles thereof, waste or scrap
720250	Ferro-silico-chromium	720230	Ferro-silico-manganese	282570	Molybdenum oxides and hydroxides
811220	Chromium, articles thereof, waste or scrap/powders	722720	Bar/rod, of silico-manganese steel, irregular coils	284170	Metallic molybdates
		722820	Bar/rod of silico-manganese steel not in coils		
		722920	Wire of silico-manganese steel		
		8111	Manganese, articles thereof, waste or scrap		
Niobium (HS 1992)		**Cobalt (HS 1992)**		**Vanadium (HS 1992)**	
HS code	**Description**	**HS code**	**Description**	**HS code**	**Description**
720293	Ferro-niobium	2605	Cobalt ores and concentrates	720292	Ferro-vanadium
		2822	Cobalt oxides and hydroxides	282530	Vanadium oxides and hydroxides
		282734	Cobalt chloride	262050	Ash or residues containing mainly vanadium
		810510	Cobalt, unwrought, matte, waste or scrap, powders	811240	Vanadium, articles thereof, waste or scrap/powders
		810590	Cobalt, articles thereof, not elsewhere specified		
* since HS 2002					

Table 19 – HS codes of refractory metal trade data

Source: UN Comtrade

Aluminum		Copper		Lead	
HS code	Description	HS code	Description	HS code	Description
76	Aluminium and articles thereof	74	Copper and articles thereof	78	Lead and articles thereof
2606	Aluminium ores and concentrates	2603	Copper ores and concentrates	2607	Lead ores and concentrates
7602	Aluminium waste or scrap	7404	Copper, copper alloy, waste or scrap	2824	Lead oxides, red lead and orange lead
262040	Ash or residues containing mainly aluminium	262030	Ash or residues containing mainly copper	7802	Lead waste or scrap
282732	Aluminium chloride	282550	Copper oxides and hydroxides	262020	Ash or residues containing mainly lead
		282741	Chloride oxides and chloride hydroxides of copper		
Nickel		**Tin**		**Zinc**	
HS code	**Description**	**HS code**	**Description**	**HS code**	**Description**
75	Nickel and articles thereof	80	Tin and articles thereof	79	Zinc and articles thereof
2604	Nickel ores and concentrates	2609	Tin ores and concentrates	2608	Zinc ores and concentrates
7503	Nickel waste or scrap	8002	Tin waste or scrap	2817	Zinc oxide and peroxide
282540	Nickel oxides and hydroxides	282737	Tin chlorides	7902	Zinc waste or scrap
720260	Ferro-nickel			262011	Ash or residues containing hard zinc spelter
				262019	Ash or residues containing hard zinc spelter
				282736	Zinc chloride
				283020	Zinc sulphide

Table 20 – HS codes of non-ferrous base metals trade data

Source: UN Comtrade

Stainless steel (HS 1992)		Alloyed steel (HS 1992)		Oil and gas pipe line steel (HS 1992)	
HS code	Description	HS code	Description	HS code	Description
730441	Stainless steel pipe or tubing, cold rolled	7224	Other alloy steel in ingots or other primary forms; semi-finished products of other alloy steel.	730410	Pipes, line, iron or steel, for oil or gas pipelines

Stainless steel (HS 1992)		Alloyed steel (HS 1992)		Oil and gas pipe line steel (HS 1992)	
HS code	Description	HS code	Description	HS code	Description
730449	Stainless steel pipe or tubing, except cold rolled	7225	Flat-rolled products of other alloy steel, of a width of 600 mm or more.	730420	Casings, tubing and drill pipe, for oil drilling
730640	Pipes and tubing, stainless steel, welded	7226	Flat-rolled products of other alloy steel, of a width of less than 600 mm.	730610	Pipe (oil/gas line) iron or steel nes, diameter <406m
730721	Flanges, stainless steel	7227	Bars and rods, hot-rolled, in irregularly wound coils, of other alloy steel.	730620	Casings,circular, iron/steel, oil/gas drilling <406mm
730722	Threaded elbows, bends and sleeves of stainless steel	722810	Bar/rod of high speed steel not in coils		
730723	Pipe fittings, butt welding of stainless steel	722830	Bar/rod, alloy steel nes,nfw hot rolled/drawn/extrude		
730729	Pipe fittings of stainless steel except butt welding	722840	Bar/rod nes, alloy steel nes, nfw forged		
731411	Woven products of stainless steel	722850	Bar/rod nes, alloy steel nes, nfw cold formed/finishe		
720421	Waste or scrap, of stainless steel	722860	Bar/rod, alloy steel nes		
7218	Stainless steel in ingots or other primary forms; semi-finished products of stainless steel.	722870	Angles, shapes and sections, alloy steel, nes		
7219	Flat-rolled products of stainless steel, of a width of 600 mm or more.	730451	Alloy steel pipe or tubing, cold rolled		
7220	Flat-rolled products of stainless steel, of a width of less than 600 mm.	730459	Alloy steel pipe or tubing, except cold rolled		
7221	Bars and rods, hot-rolled, in irregularly wound coils, of stainless steel.	730650	Pipes and tubing, alloy steel nes, welded		
7222	Other bars and rods of stainless steel; angles, shapes and sections of stainless steel.	720429	Waste or scrap, of alloy steel, other than stainless		

Stainless steel (HS 1992)		Alloyed steel (HS 1992)		Oil and gas pipe line steel (HS 1992)	
HS code	**Description**	**HS code**	**Description**	**HS code**	**Description**
7223	Wire of stainless steel.	720521	Powders, alloy steel		

Table 21 – HS codes of alloyed steel, stainless steel, and oil and gas pipeline steel trade data

Source: UN Comtrade

9.2 Origin of metal price and production data refractory and other minor metals

<table>
<tr><th>Refractory metals</th><th>Intermediate form</th><th>1960 -1993</th><th>1994</th><th>1995</th><th>1996</th><th>1997</th><th>1998</th><th>1999</th><th>2000</th><th>2001</th><th>2002</th><th>2003</th><th>2004</th><th>2005</th><th>2006</th><th>2007</th><th>2008</th></tr>
<tr><td>Chromium</td><td>Chromite ore</td><td colspan="5" rowspan="6">Price: USGS (1998a), p.1ff.</td><td colspan="5" rowspan="3">USGS (2004a), p.1</td><td colspan="4" rowspan="3">USGS (2008a), p.1</td><td colspan="2" rowspan="3">USGS(2010a), p.1</td></tr>
<tr><td></td><td>Ferro-chromium</td></tr>
<tr><td></td><td>Chromium metal</td></tr>
<tr><td>Molybdenum</td><td>Molybdenum concentrate</td><td colspan="5">USGS (2004e), p.1</td><td colspan="4">USGS (2008e), p.1</td><td colspan="2">USGS(2010d), p.1</td></tr>
<tr><td>Nio-bium</td><td>Ferro-niobium</td><td colspan="5">USGS (2004f), p.1</td><td colspan="3">USGS (2008g), p.1</td><td colspan="3">Estimated based on average value of global imports</td></tr>
<tr><td>Manga-nese</td><td>Manganese ore, 48%-50% manganese content</td><td colspan="5">USGS (2004c), p.1</td><td colspan="4">USGS (2008c), p.1</td><td colspan="2">USGS(2010c), p.1</td></tr>
<tr><td></td><td>Ferro-manganese</td><td>Not avai-lable</td><td colspan="3">Estimated based on average (1997-2008) ratio of ferro-manganese price and manganese ore price</td><td>USGS (1997b), p.1ff.</td><td>USGS(1998c), p.1ff.</td><td colspan="4">USGS (1999b), p.1ff.; USGS (2000b), p.1ff.; USGS (2001b), p.1ff.; USGS (2002b), p.1ff.</td><td>USGS (2003b), p.1ff.</td><td>USGS (2004d), p.1ff.</td><td>USGS (2005b), p.1ff.</td><td>USGS (2006b), p.1ff.</td><td>USGS (2007a), p.1ff.</td><td></td></tr>
<tr><td>Vanadium</td><td>Vanadium pentoxide</td><td colspan="6">USGS (1998a), p.1ff.</td><td colspan="4">USGS (2004g), p.1</td><td colspan="4">USGS(2008i), p.1</td><td colspan="2">USGS(2010e), p.1</td></tr>
</table>

Refractory metals	Intermediate form	1960 -1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	Ferro-vanadium	Not avai-lable	USGS (1994a), p.1ff.; USGS (1995a), p.1ff.; USGS (1996b), p.1ff.; USGS (1997c), p.1ff.				USGS(1998d), p.1ff.	USGS (1999c), p.1ff.; USGS (2000c), p.1ff.; USGS (2001c), p.1ff.; USGS (2002c), p.1ff.				USGS (2003c), p.1ff.	USGS (2004h), p.1ff.	USGS (2005c), p.1ff.	USGS (2006c), p.1ff.	USGS (2007b), p.1ff.	USGS (2008k), p.1ff.
Cobalt	Cobalt cathode	USGS (1998a), p.1ff.						USGS (2004j), p.1.				USGS (2008n), p.1				USGS(2010g), p.1	
Tungsten	Tungsten tri-Oxide	USGS (1998a), p.1ff.						USGS (2004i), p.1.				USGS (2008l)				USGS (2010f)	
Titanium	Titanium sponge metal	USGS (1998a), p.1ff.						USGS (2004k), p.1.				USGS (2008p)				USGS(2010h)	

Table 22 – Origin of price data of refractory metals

Source: Own illustration

Refractory metals	1980 -1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Chromite ore	1980 to 1983: USGS (2008b); 1984 to 2007: Raw Materials Group (RMG) (2008)															USGS (2010a)
Manganese	USGS (2008d)															
Molybdenum	USGS (2008f)															
Niobium	USGS (2008h)															
Vanadium	USGS (2008j)															

Refractory metals	1980 -1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Cobalt	USGS (2008o)															
Tungsten	USGS (2008m)															
Titanium metal	Not available	USGS (1996c), p.2	USGS (1997d), p.2	USGS (1998e), p.2	USGS (1999d), p.2	USGS (2000d), p.2	USGS (2001d), p.2	USGS (2002d), p.2	USGS (2003d), p.2	USGS (2004k), p.2	USGS (2005d), p.2	USGS (2006d), p.2	USGS (2007c), p.2	USGS (2008p), p.2	USGS (2009), p.2	USGS (2010i), p.2

Table 23 – Origin of production data of refractory metals

Source: Own illustration

Other minor metals	Intermediate form	1960 -1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Antimony	Antimony metal (99.30% to 99.50%)	USGS (1998a), p.1ff						USGS (2004l), p.1				USGS (2008q), p.1				USGS (2010j), p.1	
Beryllium	1960 to 1998: Beryllium metal (97% to 98.5%). 1999 to 2008 beryllium copper-master alloy, per beryllium content	USGS (1998a), p.1ff						USGS (2004m), p.1				USGS (2008s), p.1				USGS (2010k), p.1	

Other minor metals	Intermediate form	1960 -1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Bismuth	Bismuth metal (99.99%)	USGS (1998a), p.1ff						USGS (2004n), p.1				USGS (2008u), p.1				USGS (2010l), p.1	
Cadmium	Cadmium metal (99.95%)	USGS (1998a), p.1ff						USGS (2004o), p.1				USGS (2008w), p.1				USGS (2010m), p.1	
Gallium	Gallium metal (99.9999%)	USGS (1998a), p.1ff						USGS (2004p), p.1				USGS (2008y), p.1				USGS (2010n), p.1	
Germanium	Germanium metal (99.9%)	USGS (1998a), p.1ff						USGS (2004q), p.1				USGS (2008za), p.1				USGS (2010o), p.1	
Indium	Indium metal (99.97%)	USGS (1998a), p.1ff						USGS (2004r), p.1				USGS (2008zc), p.1				USGS (2010p), p.1	
Rare Earths	Bastnäsite concentrate, REO basis	Unavailable for 1960 to 1990. 1991 to 1994: USGS (1996d), p.1	USGS (2000e), p.1					USGS (2004s), p.1				USGS (2008ze), p.1				USGS (2010q), p.1	
Tantalum	Tantalum pentoxide	USGS (1998a), p.1ff						USGS (2004t), p.1				USGS (2008zg), p.1				USGS (2010r), p.1	
Rhenium	Rhenium metal (99.99%)	USGS (1998a), p.1ff						USGS (2004u), p.1				USGS (2008zi), p.1				USGS (2010s), p.1	
Thallium	Thallium metal (99.9%	USGS (1998a), p.1ff						USGS (2004v), p.1				USGS (2008zk), p.1				USGS (2010t), p.1	

Other minor metals	Intermediate form	1960 -1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
	to 99.999%)																

Table 24 – Origin of price data of other minor metals

Source: Own illustration

Other minor metals	1980 – 2008
Antimony	USGS (2008r)
Beryllium	USGS (2008t)
Bismuth	USGS (2008v)
Cadmium	USGS (2008x)
Gallium	USGS (2008z)
Germanium	USGS (2008zb)
Indium	USGS (2008zd)
Rare Earths	USGS (2008zf)
Tantalum	USGS (2008zh)
Rhenium	USGS (2008zj)
Thallium	USGS (2008zl)

Table 25 – Origin of production data of other minor metals

Source: Own illustration

9.3 Apparent consumption calculation

	Specific adaptations					
Country	Chromium	Manganese	Molybdenum	Niobium	Vanadium	Cobalt
Argentina			Mirror reports used for ferro-molybdenum imports (2005)			
Australia		Mirror reports used for exports (1994-2008)			Mirror reports used for all imports and exports (2000 to 2003)	
Austria			Mirror reports used for imports of roasted and unroasted molybdenum oxides (1998-2007)			
Belgium						
Brazil			Mirror reports used for imports of unroasted molybdenum (1995, 1996) and for ferro-molybdenum (1995)			
Canada						
Chile		Production of manganese ore from 1995 to 1997 interpolated				
China			Mirror reports used for exports (1994)		Mirror repports used for all exports and imports (1994-2008)	
Czech Republic				2007 apparent consumption based on trade value relative to price of ferro-niobium	Mirror repports used for all exports and imports (1994-1998)	
Finland			Mirror reports used for imports of roasted molybdenum oxide and ferro-molybdenum (2005)			
France						
Germany						
Hungary			Mirror reports used for exports of ferro-molybdenum (1994)			

	Specific adaptations					
Country	**Chromium**	**Manganese**	**Molybdenum**	**Niobium**	**Vanadium**	**Cobalt**
India	Mirror reports used for exports (1994-2008)		Mirror reports used for exports of unroasted molybdenum oxide (2005, 2006, 2008)			
Indonesia		Mirror reports used for exports (1994-2008)				
Italy						
Japan			Mirror reports used for imports of roasted molybdenum oxide (2005)			
Malaysia			Mirror reports used for ferro-molybdenum imports (1999, 2006, 2007) for imports of molybdenum articles including waste and scrap (1999, 2001, 2006, 2007) and exports of molybdenum articles including waste and scrap (1999)	2006 apparent consumption based on trade value relative to price of ferro-niobium		
Mexico			Mirror reports used for imports of ferro-molybdenum (2005 to 2008)			
Netherlands			Mirror reports used for exports of roasted molybdenum (2002, 2005)			
Norway						
Poland						
Portugal			Mirror reports used for imports of ferro-molybdenum (2005)			
Russia				Mirror reports used for imports of ferro-niobium (2006, 2007)	Mirror repports used for all exports and imports (1994-2008)	
South Africa	Mirror reports used for exports (1994-2008)					
South Korea						
Spain				Mirror reports used for imports of ferro-niobium (2007)		

	Specific adaptations					
Country	Chromium	Manganese	Molybdenum	Niobium	Vanadium	Cobalt
Sweden						
Thailand			Mirror reports used for imports of molybdenum articles including waste and scrap (2007)			
Turkey						
Ukraine		Mirror reports used for exports (1996-1999)				
United Kingdom						
USA			2004, 2005 calculation based on molybdenum contained in imports, exports reported by USGS			
Venezuela			Mirror reports used for imports of unroasted molybdenum (1995) and exports of ferro-molybdenum (2002)			

Table 26 – Country and metal specific adaptations to calculate apparent consumption

Source: Own illustration

9.3.1 Chromium

HS code	Description	Chromium content estimation	Remark
2610	Chromium ores and concentrates	Based on specific trade value in US dollars per kilogram relative to chromite ore price (compare also chapter 4.2) times average chromium oxide content in chromite ore times chromium content in chromium oxide	S. Table 28 for chromium oxide content in chromite ore and chromium content in chromium oxide
2819	Chromium oxides, hydroxides		
720241	Ferro-chromium, >4% carbon	Average chromium content of 60 percent	USGS (1998a), p.29

HS code	Description	Chromium content estimation	Remark
720249	Ferro-chromium, <4% carbon	Assumed average chromium content of 60 percent	USGS (1998a), p.29
720250	Ferro-silico-chromium	Assumed average chromium content of 60 percent	USGS (1998a), p.29
811220	Chromium, articles thereof, waste or scrap/powders	Based on specific trade value in US dollars per kilogram relative to chromium metal price (compare also chapter 4.2)	
Not available	Chromite ore production	Based on average chromium oxide content	S. Table 29

Table 27 – Overview chromium content estimation

Source: Own illustration

Chromium content in chromite ore							Data source
	Contained elements	g/mol	Factor	Subtotal	Share of total weight		
Average chromium content in chromium oxide (Cr_2O_3)	Cr	52	2	104	68%	Chromium content in chromium oxide (Cr_2O_3): 68%	
	O	16	3	48	32%		
Average chromium oxide content in chromite ore used for trade data						45%	Based on USGS (1998a), p.28
Average chromium content in chromite ore						45% * 68% = 31%	

Table 28 – Chromium content in chromite ore

Source: Own calculation

Producer of chromite ore	Average 1996 to 2008 chromium oxide content	Source
Afghanistan	44%	USGS (1996a), Appendix; USGS (1997a), Appendix; USGS (1998b), Appendix; USGS (1999a), Appendix; USGS (2000a), Appendix; USGS(2001a), Appendix; USGS (2002a), Appendix; USGS (2003a), Appendix; USGS (2004b), Appendix; USGS (2005a),Appendix; USGS (2006a) Appendix
Albania	48%	
Australia	17%	
Brazil	31%	
Burma	26%	
China	36%	
Cuba	31%	
Finland	41%	
Greece	46%	
India	40%	
Iran	49%	
Kazakhstan	39%	
Madagascar	49%	
Oman	42%	
Pakistan	25%	
Philippines	55%	
Russia	47%	
South Africa	43%	
Sudan	81%	
Turkey	52%	
Vietnam	46%	
Zimbabwe	47%	

Table 29 – Average chromite oxide content by producer

Source: Own calculation

Thousand metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	3.6	3.6	5.2	6.1	7.5	7.9	8.6	6.4	8.4	7.5	7.8	8.8	8.8	7.7	11.2
Australia	8.3	9.8	7.2	6.4	14.8	13.4	10.7	9.0	7.2	38.8	25.1	20.9	16.0	9.0	37.7
Austria	20.0	18.7	22.2	27.8	21.3	18.9	25.5	28.2	19.6	25.4	30.8	29.1	27.4	39.7	35.9
Belgium	0.0	68.0	58.2	55.7	66.7	60.6	81.3	67.8	79.1	95.7	111.1	115.7	186.3	242.0	208.5
Brazil	69.7	86.1	77.1	55.4	104.4	87.8	125.2	85.9	64.2	93.6	134.3	131.4	133.2	139.8	119.5
Canada	38.9	45.4	44.8	43.7	38.2	36.0	29.8	25.3	34.2	29.3	19.2	23.2	20.7	19.0	22.4
Chile	3.0	3.6	3.2	4.3	5.8	3.1	5.2	5.2	4.0	6.5	3.4	5.4	4.1	4.9	6.4
China	13.4	38.4	59.3	89.6	69.8	109.9	96.9	115.6	168.7	304.6	489.7	544.1	776.6	1,607.7	1,576.2
Czech Republic	5.7	23.2	13.5	17.3	22.9	20.5	28.9	26.1	28.7	11.3	12.4	13.0	14.1	22.2	16.8
Finland	87.1	100.8	98.8	104.1	106.9	116.0	151.7	114.7	113.5	139.2	144.7	140.7	141.7	101.0	139.7
France	148.1	163.1	130.4	166.5	176.4	176.8	191.2	157.3	190.6	162.6	139.8	120.6	101.8	64.9	67.7
Germany	218.0	272.7	210.6	248.8	274.5	252.4	248.2	239.7	234.1	298.7	275.1	287.1	291.8	295.7	345.2
Hungary	1.1	1.5	2.2	1.1	1.0	1.1	1.4	1.3	1.4	0.6	0.6	0.9	1.3	1.1	0.8
India	134.1	261.8	214.4	213.1	203.6	261.3	351.2	298.1	386.0	344.2	519.5	587.2	651.2	481.3	500.0
Indonesia	0.5	0.7	0.1	0.2	0.2	0.2	0.9	1.1	1.1	1.1	0.8	1.0	1.1	0.4	3.0
Italy	120.7	81.4	124.1	148.5	166.9	188.1	184.7	190.1	228.8	223.1	239.8	262.5	278.2	255.5	238.3
Japan	442.4	572.5	529.7	561.3	431.7	408.4	524.9	487.3	504.2	573.3	622.2	625.8	546.5	610.4	615.3
Malaysia	0.7	0.8	0.8	0.8	0.7	3.3	1.2	2.8	1.1	1.5	1.7	1.2	2.2	5.7	7.5
Mexico	4.3	5.1	7.3	7.5	7.2	9.2	7.0	5.0	8.1	10.2	12.1	10.9	16.1	19.9	12.9
Netherlands	8.2	72.1	78.9	46.6	69.2	91.2	58.0	55.9	60.4	10.4	63.1	50.9	65.8	141.3	103.3
Norway	0.4	0.5	0.4	0.5	0.4	0.3	0.5	0.5	0.3	0.4	0.5	1.0	1.4	0.9	0.6
Poland	2.6	7.5	11.0	8.0	8.9	8.7	10.1	8.8	6.2	8.1	9.4	8.3	10.0	12.9	13.9
Portugal	1.2	1.5	1.1	1.2	1.2	1.4	1.4	1.6	1.6	1.4	1.3	0.9	1.2	1.3	1.1
Russia	n/a	n/a	60.8	84.9	46.5	66.5	82.0	86.8	76.7	103.1	67.5	96.7	221.1	171.1	282.6
South Africa	416	696	593	631	825	813	799	534	711	846	807	824	720	918	823
South Korea	112.7	123.3	143.0	188.0	183.8	240.9	226.0	201.8	225.5	308.1	364.9	325.5	266.7	262.4	263.3
Spain	94.6	94.3	92.7	118.6	118.0	137.1	133.7	156.9	141.2	350.7	133.6	125.7	153.3	139.9	126.5
Sweden	21.3	49.4	41.0	47.5	48.1	47.8	53.9	56.7	67.2	52.2	44.8	52.1	51.5	76.1	69.6
Thailand	3.2	2.5	3.5	3.6	2.8	3.4	6.2	4.1	4.6	6.5	7.8	10.5	12.1	15.0	14.3
Turkey	335.4	540.3	350.8	535.7	382.4	145.1	104.7	93.6	46.2	11.6	54.4	68.5	40.1	-14.9	-71.3

Thousand metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Ukraine	n/a	n/a	17.9	19.3	14.7	17.6	30.1	26.9	21.8	28.3	24.8	22.9	22.4	27.8	22.4
United Kingdom	101.5	67.5	79.6	77.1	73.3	70.2	75.9	65.4	60.1	50.5	73.0	42.0	39.8	34.2	51.5
USA	210.8	342.6	281.3	281.7	286.1	390.6	202.1	99.0	123.2	149.4	158.6	272.7	271.7	148.3	233.8
Venezuela	0.7	0.6	0.5	0.9	0.7	0.2	-2.2	0.1	0.3	-5.0	0.3	0.6	0.7	0.5	-0.6
Total	**2,657.9**	**3,785.7**	**3,392.5**	**3,868.2**	**3,831.8**	**3,843.2**	**3,934.6**	**3,307.2**	**3,665.1**	**4,427.9**	**4,780.6**	**4,850.1**	**5,128.6**	**5,940.1**	**6,119.9**

Table 30 – Chromium apparent consumption

Source: Own estimation

Metric tons of chromium/ thousand metric tons of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	1.1	1.0	1.3	1.5	1.8	2.1	1.9	1.6	1.9	1.5	1.5	1.6	1.6	1.4	2.0
Australia	1.0	1.2	0.9	0.7	1.7	1.6	1.5	1.3	1.0	5.1	3.4	2.7	2.0	1.1	4.9
Austria	4.5	3.7	5.0	5.4	4.0	3.6	4.5	4.8	3.2	4.1	4.7	4.1	3.8	5.2	4.7
Belgium	n/a	4.8	4.4	4.2	4.8	4.5	5.7	5.0	5.6	6.9	7.7	9.2	12.9	17.9	15.7
Brazil	2.7	3.4	3.1	2.1	4.1	3.5	4.5	3.2	2.2	3.0	4.1	4.2	4.3	4.1	3.5
Canada	2.8	3.1	3.0	2.8	2.4	2.2	1.8	1.7	2.1	1.8	1.2	1.5	1.3	1.2	1.5
Chile	2.9	3.6	2.7	3.7	4.9	2.4	3.9	4.2	3.2	4.7	2.2	3.5	2.5	3.0	4.2
China	0.1	0.4	0.6	0.8	0.6	0.9	0.8	0.8	0.9	1.4	1.7	1.5	1.8	3.3	3.2
Czech Republic	0.8	3.2	2.1	2.6	3.5	3.7	4.6	4.1	4.4	1.7	1.8	2.1	2.1	3.2	2.6
Finland	25.5	31.7	29.9	27.9	27.0	29.3	37.0	29.1	28.4	29.2	29.9	29.7	28.0	22.8	31.6
France	8.2	9.0	7.4	8.4	8.8	8.8	9.1	8.1	9.4	8.2	6.7	6.2	5.1	3.4	3.8
Germany	5.3	6.5	5.3	5.5	6.2	6.0	5.4	5.4	5.2	6.7	5.9	6.4	6.2	6.1	7.5
Hungary	0.6	0.8	1.2	0.7	0.5	0.6	0.7	0.6	0.7	0.3	0.3	0.5	0.6	0.5	0.4
India	7.0	11.9	9.0	8.7	8.7	10.8	13.0	10.9	13.4	10.8	15.9	12.8	13.2	9.1	8.7
Indonesia	0.2	0.2	0.0	0.0	0.1	0.1	0.3	0.4	0.4	0.5	0.2	0.3	0.3	0.1	0.8
Italy	4.6	2.9	5.2	5.7	6.5	7.6	6.9	7.2	8.8	8.2	8.4	8.9	8.8	8.0	7.8
Japan	4.5	5.6	5.4	5.4	4.6	4.3	4.9	4.7	4.7	5.2	5.5	5.6	4.7	5.1	5.2
Malaysia	0.3	0.3	0.3	0.3	0.3	1.2	0.3	0.7	0.2	0.4	0.3	0.2	0.4	0.9	1.2

Metric tons of chromium/ thousand metric tons of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Mexico	0.4	0.4	0.6	0.5	0.5	0.6	0.5	0.4	0.6	0.7	0.7	0.7	1.0	1.1	0.7
Netherlands	1.3	11.2	12.5	7.0	10.9	15.0	10.2	9.3	9.9	1.6	9.2	7.4	10.3	19.2	15.1
Norway	0.9	1.1	0.8	0.8	0.7	0.4	0.8	0.8	0.5	0.5	0.7	1.4	2.1	1.2	1.0
Poland	0.2	0.6	1.1	0.7	0.9	1.0	1.0	1.0	0.7	0.9	0.9	1.0	1.0	1.2	1.4
Portugal	1.7	1.8	1.3	1.3	1.3	1.4	1.3	2.1	1.8	1.4	0.9	0.6	0.9	0.9	0.8
Russia	n/a	n/a	1.2	1.8	1.1	1.3	1.4	1.5	1.3	1.7	1.0	1.5	3.1	2.4	4.1
South Africa	48.8	79.6	74.1	76	103.7	103.5	94.2	60.5	78.2	89.2	84.9	86.8	74.1	100.9	99.5
South Korea	3.3	3.4	3.7	4.4	4.6	5.9	5.2	4.6	5.0	6.7	7.7	6.8	5.5	5.1	4.9
Spain	7.0	6.8	7.6	8.7	8.0	9.2	8.4	9.5	8.6	21.5	7.6	7.1	8.3	7.4	6.8
Sweden	4.3	10.0	8.4	9.2	9.3	9.4	10.3	10.3	11.7	9.1	7.5	9.1	9.4	13.4	13.4
Thailand	2.2	1.2	1.6	1.7	1.5	2.2	2.9	1.9	1.8	1.8	1.7	2.0	2.3	2.7	2.7
Turkey	26.6	41.0	25.7	37.0	27.0	10.1	7.3	6.2	2.8	0.6	2.7	3.3	1.7	-0.6	-2.7
Ukraine	n/a	n/a	0.8	0.8	0.6	0.6	0.9	0.8	0.6	0.8	0.6	0.6	0.5	0.6	0.6
United Kingdom	5.9	3.8	4.4	4.2	4.2	4.3	5.0	4.8	5.1	3.8	5.3	3.2	2.9	2.4	3.8
USA	2.3	3.6	2.9	2.9	2.9	4.0	2.0	1.1	1.3	1.6	1.6	2.9	2.8	1.5	2.6
Venezuela	0.2	0.2	0.1	0.2	0.2	0.1	-0.6	0.0	0.1	-1.3	0.1	0.1	0.1	0.1	-0.1

Table 31 – Chromium material composition of product

Source: Own estimation

9.3.2 Manganese

HS code	Description	Manganese content estimation	Remark
2602	Manganese ores, concentrates, iron ores >20% Manganese	Assumed average manganese content of 49%	USGS (1998a), p.86
2820	Manganese oxides	Based on specific trade value in US dollars per kilogram relative to manganese ore price	Compare chapter 4.2
720211	Ferro-manganese, >2% carbon	Based on specific trade value in US dollars per kilogram relative to ferro-manganese price	Compare chapter 4.2

720219	Ferro-manganese, <2% carbon	Based on specific trade value in US dollars per kilogram relative to ferro-manganese price	Compare chapter 4.2
720230	Ferro-silico-manganese	Based on specific trade value in US dollars per kilogram relative to ferro-manganese price	Compare chapter 4.2
722720	Bar/rod, of silico-manganese steel, irregular coils	Based on specific trade value in US dollars per kilogram relative to ferro-manganese price	Compare chapter 4.2
722820	Bar/rod of silico-manganese steel not in coils	Based on specific trade value in US dollars per kilogram relative to ferro-manganese price	Compare chapter 4.2
722920	Wire of silico-manganese steel	Based on specific trade value in US dollars per kilogram relative to ferro-manganese price	Compare chapter 4.2
8111	Manganese, articles thereof, waste or scrap	Based on specific trade value in US dollars per kilogram relative to ferro-manganese price	Compare chapter 4.2

Table 32 – Overview manganese content estimation

Source: Own illustration

Thousand metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	33	33	41	61	26	33	41	39	47	49	54	67	75	54	66
Australia	225	216	96	134	-24	88	117	107	166	22	78	112	174	161	312
Austria	33	26	32	40	44	39	22	29	23	40	42	67	57	85	67
Belgium	104	125	129	93	131	126	137	140	143	126	120	136	139	161	110
Brazil	277	282	343	179	683	779	633	565	540	623	352	343	755	215	408
Canada	120	108	147	90	94	90	64	74	71	103	110	101	106	144	130
Chile	16	17	17	21	21	18	23	24	27	26	28	31	30	15	14
China	562	1,125	1,444	1,272	921	533	492	779	831	891	2,073	2,156	2,558	4,369	3,559
Czech Republic	58	59	56	64	55	39	32	40	32	56	47	34	65	49	49
Finland	40	43	17	28	28	26	31	30	39	27	33	23	29	35	36
France	262	363	342	289	374	250	370	256	181	144	155	143	120	140	204
Germany	313	354	304	320	318	283	301	314	335	289	276	332	337	362	337
Hungary	12	14	11	13	15	16	17	17	19	18	13	16	25	26	31
India	449	443	479	536	485	521	410	450	399	474	539	731	739	886	1,122

Thousand metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Indonesia	68	108	112	86	41	29	54	29	51	53	56	54	51	8	-13
Italy	224	191	180	153	207	168	194	172	249	234	294	263	334	335	258
Japan	739	826	776	822	766	796	701	766	767	881	913	832	955	1,022	911
Malaysia	28	34	49	41	13	49	56	41	35	45	61	47	52	64	33
Mexico	91	145	173	178	175	141	135	120	129	147	184	188	151	158	215
Netherlands	14	25	29	29	61	35	18	-1	21	64	58	75	81	108	71
Poland	100	93	98	95	87	73	125	102	107	120	149	64	89	146	87
Portugal	10	12	13	14	13	12	13	16	25	26	15	26	39	39	23
Russia	0	0	262	192	187	346	499	453	410	452	380	378	483	567	481
South Korea	281	319	313	344	304	312	330	325	359	362	395	332	309	476	473
Spain	238	154	104	52	83	58	90	70	89	108	153	76	100	132	233
Sweden	15	33	30	30	44	59	53	36	26	39	32	36	41	60	53
Thailand	22	34	36	28	24	24	24	23	27	35	40	38	49	47	43
Turkey	119	125	133	147	150	146	159	132	220	228	215	221	222	268	215
Ukraine	0	0	321	419	15	211	223	288	442	729	884	717	830	639	961
United Kingdom	190	244	221	216	210	180	162	147	165	146	126	152	167	153	141
USA	762	767	913	745	855	928	988	747	761	709	941	802	1,082	772	845
Venezuela	32	25	20	15	19	8	24	32	23	13	48	30	21	41	34
Total	**5,418**	**6,347**	**7,271**	**6,796**	**6,457**	**6,534**	**6,665**	**6,502**	**6,879**	**7,450**	**8,991**	**8,754**	**10,406**	**11,964**	**11,640**

Table 33 – Manganese apparent consumption

Source: Own estimation

Metric tons manganese/ thousand metric tons of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	10	9	10	15	6	9	9	10	11	10	11	12	13	10	12
Australia	27	26	11	15	-3	11	16	15	22	3	10	14	22	20	41

Metric tons manganese/ thousand metric tons of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Austria	8	5	7	8	8	8	4	5	4	6	6	10	8	11	9
Belgium	7	9	10	7	9	9	10	10	10	9	8	11	10	12	8
Brazil	11	11	14	7	26	31	23	21	18	20	11	11	24	6	12
Canada	9	8	10	6	6	6	4	5	4	6	7	7	7	9	9
Chile	16	17	14	18	18	14	17	19	21	19	18	20	18	9	9
China	6	12	14	12	8	4	4	5	5	4	7	6	6	9	7
Czech Republic	8	8	9	9	8	7	5	6	5	8	7	5	10	7	8
Finland	12	14	5	8	7	6	8	8	10	6	7	5	6	8	8
France	15	20	19	15	19	12	18	13	9	7	7	7	6	7	11
Germany	8	8	8	7	7	7	6	7	7	6	6	7	7	7	7
Hungary	6	7	6	8	8	9	9	9	9	9	7	8	12	11	15
India	23	20	20	22	21	21	15	16	14	15	17	16	15	17	19
Indonesia	21	26	27	23	15	10	19	10	21	26	15	15	14	2	-3
Italy	9	7	8	6	8	7	7	6	10	9	10	9	11	10	8
Japan	8	8	8	8	8	8	7	7	7	8	8	7	8	8	8
Malaysia	14	14	15	14	7	18	15	10	7	11	11	9	9	11	5
Mexico	9	12	13	12	12	9	9	9	9	10	11	12	9	9	12
Netherlands	2	4	5	4	10	6	3	-0	3	10	9	11	13	15	10
Poland	9	8	9	8	9	8	12	12	13	13	14	8	9	14	9
Portugal	14	15	15	15	14	12	12	23	27	26	11	19	28	28	16
Russia	n/a	n/a	5	4	4	7	8	8	7	7	6	6	7	8	7
South Korea	8	9	8	8	8	8	8	7	8	8	8	7	6	9	9
Spain	18	11	9	4	6	4	6	4	5	7	9	4	5	7	13
Sweden	3	7	6	6	9	12	10	6	4	7	5	6	7	11	10
Thailand	15	16	17	13	13	16	11	11	11	10	9	7	9	9	8
Turkey	9	9	10	10	11	10	11	9	13	12	10	11	10	10	8
Ukraine	n/a	n/a	14	16	1	8	7	9	13	20	23	19	20	15	26
United Kingdom	11	14	12	12	12	11	11	11	14	11	9	12	12	11	10
USA	8	8	10	8	9	10	10	8	8	8	9	8	11	8	9

Metric tons manganese/ thousand metric tons of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Venezuela	9	7	5	4	5	2	6	8	5	3	10	6	4	8	8

Table 34 – Manganese material composition of product

Source: Own estimation

9.3.3 Molybdenum

HS code	Description	Molybdenum content estimation	Remark
261310	Molybdenum concentrates, roasted	Based on specific trade value in US dollars per kilogram relative to molybdenum oxide price	Compare chapter 4.2
261390	Molybdenum ores and concentrates except roasted	Based on specific trade value in US dollars per kilogram relative to molybdenum oxide price	Compare chapter 4.2
720270	Ferro-molybdenum	Based on specific trade value in US dollars per kilogram relative to molybdenum oxide price	Compare chapter 4.2
8102	Molybdenum and articles thereof, waste or scrap	Based on specific trade value in US dollars per kilogram relative to molybdenum oxide price	Compare chapter 4.2
282570	Molybdenum oxides and hydroxides	Based on specific trade value in US dollars per kilogram relative to molybdenum oxide price	Compare chapter 4.2
284170	Metallic molybdates	Based on specific trade value in US dollars per kilogram relative to molybdenum oxide price	Compare chapter 4.2

Table 35 – Overview molybdenum content estimation

Source: Own illustration

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	417	321	392	368	490	394	473	774	640	506	506	847	749	613	812

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Australia	836	562	747	650	831	563	615	663	536	413	345	496	471	359	475
Austria	1,144	898	918	994	-759	-1,172	867	755	914	916	1,028	761	1,997	1,762	2,123
Brazil	2,762	1,287	1,457	2,345	2,757	2,029	2,435	2,679	2,245	2,621	2,310	2,530	2,698	2,739	2,770
Canada	6,953	6,655	6,717	5,599	6,343	5,467	6,510	6,107	5,537	6,048	6,747	5,030	4,683	5,837	5,110
Chile	864	6,912	4,504	7,416	3,894	9,666	12,546	7,211	11,022	17,436	21,040	22,854	14,583	16,094	8,198
China	4,214	8,965	15,570	14,844	2,717	6,434	2,940	3,499	5,599	5,615	14,105	23,786	26,071	41,293	66,498
Czech Republic	508	410	326	198	432	226	415	627	501	630	756	1,022	979	1,010	1,148
Finland	2,951	2,112	1,914	2,129	2,840	2,245	2,560	2,468	2,463	3,085	2,823	2,586	2,846	2,702	2,187
France	6,996	4,713	4,079	4,476	7,481	4,161	5,157	5,002	4,164	3,976	3,339	3,788	3,917	3,599	4,515
Germany	11,802	7,205	7,137	7,098	14,598	10,031	10,532	12,562	10,485	7,874	8,204	9,950	12,448	11,726	11,357
Hungary	51	174	223	140	221	103	244	181	250	201	157	171	249	207	171
India	2,463	928	1,110	1,408	1,614	1,377	1,265	1,683	1,751	1,689	1,470	1,658	2,293	2,068	2,207
Indonesia	84	78	107	43	83	124	397	194	103	53	28	37	72	88	145
Italy	5,991	3,549	3,577	3,951	6,711	4,349	4,464	4,724	4,122	3,916	4,712	5,294	5,394	5,396	5,930
Japan	18,308	14,360	13,551	15,888	19,770	12,560	15,852	15,801	14,143	14,824	14,312	18,384	19,768	17,570	19,683
Malaysia	91	35	78	59	106	195	144	79	77	66	39	32	48	40	43
Mexico	795	1,231	432	378	1,281	2,897	4,051	2,772	1,273	2,214	1,610	1,448	2,389	368	56
Netherlands	1,885	3,697	2,711	4,588	5,846	4,867	4,648	5,070	-459	736	2,423	3,514	2,272	1,667	7,079
Norway	38	47	52	51	62	28	38	48	48	66	52	52	21	45	37
Poland	566	439	417	413	620	380	520	508	441	414	570	617	633	674	784
Portugal	71	57	92	80	114	87	88	94	72	56	62	60	37	42	33
Russia	n/a	n/a	83	95	-528	1,027	1,784	1,379	2,111	2,234	2,356	2,423	1,892	2,209	2,556
South Africa	1,556	1,133	1,183	1,275	1,973	1,544	1,517	1,384	1,730	1,761	1,117	876	1,355	1,418	1,226
South Korea	2,602	2,140	2,284	2,052	3,454	3,456	3,177	3,763	4,182	4,096	3,869	5,177	4,906	4,869	3,293
Spain	4,077	2,613	2,856	3,156	3,597	2,444	2,637	3,318	3,463	3,325	2,595	2,962	3,767	3,657	3,480
Sweden	6,931	4,524	3,873	4,949	7,090	4,489	4,788	4,820	4,410	4,464	4,329	4,957	5,773	5,066	5,116
Thailand	83	84	137	94	108	139	185	158	113	140	112	126	137	111	173
Turkey	267	218	279	272	402	307	296	397	377	376	331	598	485	694	872
Ukraine	n/a	n/a	418	-147	301	99	866	788	241	775	1,019	1,147	884	785	1,226
United Kingdom	375	1,379	1,832	2,215	1,605	2,041	1,121	1,789	1,738	-85	-767	-363	1,199	2,177	2,538

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
USA	22,702	42,537	43,820	45,361	38,248	34,360	36,254	29,834	28,264	25,977	40,375	50,093	44,474	46,763	39,333
Venezuela	69	53	57	73	47	41	56	43	36	24	23	40	24	21	26
Total	**108,450**	**119,317**	**122,934**	**132,511**	**134,350**	**116,960**	**129,442**	**121,175**	**112,593**	**116,443**	**141,996**	**172,954**	**169,511**	**183,667**	**201,200**

Table 36 – Molybdenum apparent consumption

Source: Own estimation

Grams molybdenum/ Metric tons of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	127	90	96	88	116	104	106	188	147	100	99	157	135	114	147
Australia	99	66	89	74	93	69	86	94	71	55	47	64	60	45	62
Austria	260	180	207	192	-144	-225	152	129	148	146	157	108	280	233	280
Brazil	107	51	58	90	107	81	87	100	76	84	70	80	87	81	82
Canada	500	462	456	360	398	337	392	400	346	380	414	328	302	371	344
Chile	831	6,816	3,823	6,354	3,325	7,487	9,280	5,783	8,618	12,662	13,325	14,869	8,963	9,661	5,383
China	45	94	154	136	24	52	23	23	31	25	50	67	62	84	133
Czech Republic	72	57	50	29	66	40	67	99	77	93	108	165	143	143	180
Finland	863	665	580	570	719	568	625	627	615	647	584	546	563	610	495
France	388	260	231	226	372	206	246	259	206	201	161	194	197	187	253
Germany	289	171	179	158	331	238	227	280	233	176	177	223	264	242	248
Hungary	26	93	119	83	122	57	130	93	122	101	80	87	119	93	82
India	128	42	47	58	69	57	47	62	61	53	45	36	46	39	38
Indonesia	26	19	26	11	31	43	140	70	42	26	8	10	19	22	37
Italy	229	128	150	153	261	175	167	178	158	145	165	180	171	169	194
Japan	186	141	137	152	211	133	149	154	131	134	127	163	170	146	166
Malaysia	44	14	24	20	56	70	40	19	16	17	7	6	8	7	7
Mexico	78	101	33	27	90	190	259	208	91	146	96	89	146	21	3
Netherlands	305	577	429	691	917	801	820	840	-75	112	354	508	357	226	1,033

Grams molybdenum/ Metric tons of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Norway	83	94	101	86	98	47	56	74	69	94	71	74	30	64	66
Poland	51	37	40	36	63	43	50	58	53	46	54	74	63	63	81
Portugal	95	68	107	89	121	83	81	130	79	56	45	43	26	30	24
Russia	n/a	n/a	2	2	-12	20	30	23	35	36	36	37	27	31	37
South Africa	183	130	148	153	248	197	179	157	190	186	118	92	139	156	148
South Korea	77	58	59	48	87	84	74	86	92	88	81	108	101	95	61
Spain	303	189	235	231	243	164	166	201	211	204	147	166	205	193	187
Sweden	1,395	913	789	961	1,376	886	916	874	766	782	724	866	1,056	893	984
Thailand	56	39	64	45	59	91	88	74	45	39	25	24	26	20	33
Turkey	21	17	21	19	28	21	21	27	23	21	16	29	21	27	33
Ukraine	n/a	n/a	19	-6	12	4	27	24	7	21	26	30	22	18	33
United Kingdom	22	78	102	120	93	125	74	132	149	-6	-56	-27	86	152	188
USA	249	447	459	461	388	353	356	331	309	277	405	528	451	476	431
Venezuela	20	15	15	18	13	13	15	11	9	6	5	8	5	4	6

Table 37 – Molybdenum material composition of product

Source: Own estimation

9.3.4 Niobium

HS code	Description	Niobium content estimation	Remark
720293	Ferro-niobium	Assumed average niobium content of 65 percent (average content US imports 2003 to 2007)	USGS (2003f), Appendix; USGS (2004w), Appendix; USGS (2005e), Appendix; USGS (2006e), Appendix; USGS (2007e), Appendix

Table 38 – Overview niobium content estimation

Source: Own illustration

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	27	21	54	38	44	95	63	36	72	45	76	109	107	83	89
Australia	111	61	237	98	210	59	25	6	4	23	36	234	246	73	161
Austria	-66	-84	145	240	403	252	235	353	506	1,084	607	585	622	587	731
Belgium	0	374	446	431	462	401	565	687	570	519	518	613	717	1,094	1,237
Brazil	1,740	2,516	6,258	2,615	5,697	4,618	3,647	8,821	8,587	16,022	15,903	24,173	9,555	10,602	10,701
Canada	3,337	2,620	1,810	1,840	2,193	2,141	1,851	1,742	1,499	432	464	425	494	313	2,046
Chile	33	78	88	71	69	27	45	0	0	0	9	16	14	15	1
China	50	187	176	96	369	610	800	933	1,068	2,072	2,324	6,256	7,713	9,694	15,312
Czech Republic	28	31	26	32	37	27	16	17	59	65	209	183	178	165	246
Finland	221	237	210	233	292	275	305	277	315	321	306	311	321	371	492
France	624	596	779	726	832	775	851	877	873	883	1,154	1,613	1,300	1,194	1,494
Germany	1,070	1,267	1,636	2,003	1,997	1,206	1,410	1,580	1,750	1,615	1,812	2,239	3,252	3,268	3,388
Hungary	18	0	14	0	0	0	0	0	0	54	0	0	0	0	88
India	12	87	59	67	107	141	123	249	170	269	431	551	994	1,099	1,209
Indonesia	29	54	49	129	44	20	64	0	1	13	21	89	24	83	11
Italy	704	912	775	914	907	741	834	942	996	925	911	1,594	1,404	1,875	1,771
Japan	2,367	3,247	3,093	3,234	4,234	4,430	3,616	4,072	4,420	5,303	4,579	4,684	6,120	5,755	7,113
Malaysia	6	1	1	2	1	2	10	20	7	9	125	98	90	93	107
Mexico	91	213	283	323	454	474	527	400	461	500	627	1,089	1,371	1,544	1,218
Norway	0	0	0	3	2	3	17	17	1	16	2	1	0	36	2
Poland	-5	47	20	27	44	42	34	15	33	40	52	68	140	115	129
Portugal	1	1	1	2	3	8	4	7	7	4	4	3	2	2	3
Russia	n/a	n/a	-4	90	192	38	255	-32	88	83	50	23	-27	36	-3
South Africa	66	112	59	58	145	37	76	97	88	52	99	201	322	393	277
South Korea	306	231	250	410	506	709	443	619	802	995	838	1,689	1,637	2,367	2,288
Spain	203	193	268	239	283	142	141	158	210	200	334	575	257	60	327
Sweden	278	169	185	282	390	385	430	400	479	471	546	729	735	696	468
Thailand	0	1	1	1	1	0	2	1	2	3	2	4	18	21	38
Turkey	1	2	0	12	44	51	19	30	108	122	137	256	283	234	396
Ukraine	n/a	n/a	102	36	154	102	87	249	227	558	733	904	1,224	1,257	832

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
United Kingdom	540	487	584	542	684	589	936	754	639	708	773	713	659	936	834
USA	2,440	3,328	2,872	4,484	5,233	4,689	4,617	4,944	4,220	4,123	5,040	5,340	7,843	7,400	8,735
Venezuela	2	18	11	4	8	3	12	38	20	26	33	103	81	71	7
Total	**14,233**	**17,006**	**20,489**	**19,280**	**26,042**	**23,092**	**22,061**	**28,308**	**28,281**	**37,556**	**38,756**	**55,471**	**47,696**	**51,531**	**61,749**

Table 39 – Niobium apparent consumption

Source: Own estimation

Grams niobium/ Metric ton of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	8.2	5.8	13.3	9.0	10.5	25.0	14.1	8.9	16.6	8.9	14.7	20.2	19.3	15.3	16.1
Australia	13.1	7.2	28.2	11.0	23.5	7.2	3.6	0.8	0.5	3.0	4.8	30.2	31.2	9.2	21.2
Austria	-15.0	-16.8	32.6	46.3	76.3	48.4	41.1	60.2	81.8	173.2	93.0	83.1	87.2	77.5	96.2
Belgium		32.2	41.2	40.1	40.4	36.7	48.5	63.8	50.2	46.7	44.3	58.9	61.7	102.4	115.9
Brazil	67.6	100.3	248.0	100.0	221.2	184.7	130.9	330.2	290.0	514.4	483.2	764.7	309.2	313.8	317.4
Canada	240.1	181.7	122.8	118.3	137.7	131.9	111.6	114.0	93.7	27.1	28.5	27.7	31.9	19.9	137.8
Chile	31.9	76.9	74.5	61.0	58.6	21.1	33.2	0.0	0.0	0.0	5.9	10.4	8.8	9.1	0.9
China	0.5	2.0	1.7	0.9	3.2	4.9	6.3	6.2	5.9	9.3	8.3	17.6	18.2	19.8	30.6
Czech Republic	4.0	4.3	4.0	4.7	5.8	4.7	2.6	2.7	9.0	9.7	29.7	29.5	25.9	23.4	38.5
Finland	64.6	74.5	63.5	62.4	73.9	69.6	74.4	70.3	78.8	67.4	63.3	65.6	63.5	83.6	111.4
France	34.6	32.9	44.2	36.7	41.3	38.4	40.6	45.3	43.1	44.7	55.6	82.8	65.5	62.0	83.6
Germany	26.2	30.1	41.1	44.5	45.3	28.7	30.4	35.3	38.9	36.0	39.1	50.3	68.9	67.3	73.9
Hungary	9.2	0.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0	27.2	0.0	0.0	0.0	0.0	41.9
India	0.6	4.0	2.5	2.8	4.6	5.8	4.6	9.1	5.9	8.5	13.2	12.0	20.1	20.7	20.9
Indonesia	9.1	13.1	11.9	33.7	16.4	7.0	22.6	0.0	0.4	6.4	5.6	24.2	6.4	21.0	2.8
Italy	26.9	32.8	32.4	35.4	35.3	29.8	31.1	35.5	38.2	34.2	31.8	54.3	44.4	58.6	57.9
Japan	24.1	31.9	31.3	30.9	45.3	47.0	34.0	39.6	41.0	48.0	40.6	41.6	52.7	47.9	59.9
Malaysia	2.9	0.5	0.2	0.8	0.7	0.5	2.6	4.8	1.5	2.2	21.9	18.5	15.4	15.1	16.7
Mexico	8.9	17.6	21.4	22.7	31.9	31.0	33.7	30.1	32.9	33.0	37.5	67.3	84.1	87.9	70.8

Grams niobium/ Metric ton of steel production	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Norway	0.3	0.0	0.0	5.0	3.7	4.3	25.2	26.4	1.9	23.4	3.0	0.9	0.4	50.9	2.9
Poland	-0.4	4.0	1.9	2.3	4.4	4.8	3.3	1.6	3.9	4.4	4.9	8.1	14.0	10.8	13.2
Portugal	0.9	1.3	1.5	1.8	3.0	7.3	3.6	10.2	7.8	3.9	2.8	2.3	1.8	1.2	2.5
Russia	n/a	n/a	-0.1	1.8	4.4	0.7	4.3	-0.5	1.5	1.4	0.8	0.3	-0.4	0.5	-0.0
South Africa	7.7	12.8	7.4	6.9	18.2	4.8	9.0	11.0	9.6	5.5	10.4	21.2	33.1	43.2	33.5
South Korea	9.1	6.3	6.4	9.6	12.7	17.3	10.3	14.1	17.7	21.5	17.6	35.3	33.8	46.1	42.7
Spain	15.1	14.0	22.0	17.5	19.1	9.5	8.9	9.6	12.8	12.3	18.9	32.3	14.0	3.2	17.5
Sweden	56.0	34.1	37.7	54.8	75.7	76.0	82.2	72.6	83.2	82.4	91.3	127.4	134.5	122.6	90.1
Thailand		0.6	0.5	0.3	0.8	0.3	1.0	0.5	0.6	0.9	0.4	0.7	3.5	3.9	7.3
Turkey	0.1	0.2	0.0	0.9	3.1	3.6	1.3	2.0	6.6	6.7	6.7	12.2	12.1	9.1	14.8
Ukraine	n/a	n/a	4.6	1.4	6.3	3.7	2.7	7.5	6.7	15.1	18.9	23.4	29.9	29.3	22.3
United Kingdom	31.2	27.7	32.5	29.3	39.5	36.1	61.8	55.7	54.8	53.3	56.1	53.8	47.5	65.4	61.7
USA	26.7	35.0	30.1	45.5	53.0	48.1	45.4	54.9	46.1	44.0	50.6	56.3	79.6	75.4	95.6
Venezuela	0.5	5.1	2.7	1.0	2.3	1.0	3.1	9.9	4.8	6.7	7.3	21.0	16.6	14.1	1.7

Table 40 – Niobium material composition of product

Source: Own estimation

9.3.5 Cobalt

HS code	Description	Cobalt content estimation	Remark
2605	Cobalt ores and concentrates	Based on specific trade value in US dollars per kilogram relative to cobalt cathode price	Compare chapter 4.2
2822	Cobalt oxides and hydroxides	Based on specific trade value in US dollars per kilogram relative to cobalt cathode price	Compare chapter 4.2
282734	Cobalt chloride	Based on specific trade value in US dollars per kilogram relative to cobalt cathode price	Compare chapter 4.2

HS code	Description	Cobalt content estimation	Remark
810510	Cobalt, unwrought, matte, waste or scrap, powders	Based on specific trade value in US dollars per kilogram relative to cobalt cathode price	Compare chapter 4.2
810590	Cobalt, articles thereof, nes	Based on specific trade value in US dollars per kilogram relative to cobalt cathode price	Compare chapter 4.2

Table 41 – Overview cobalt content estimation

Source: Own illustration

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	56	29	75	67	66	77	73	77	91	87	86	119	98	62	63
Australia	2,271	2,254	2,834	2,612	2,385	2,738	3,285	3,246	4,565	2,286	1,398	2,834	2,433	2,667	3,493
Austria	298	96	266	294	299	292	494	375	231	315	527	525	405	569	608
Belgium	0	365	1	73	141	299	83	99	251	450	470	137	-3,793	-3,716	-3,768
Brazil	663	678	660	608	562	614	805	948	1,087	1,112	863	1,013	936	1,193	1,505
Canada	1,576	2,085	1,389	296	-146	103	1,084	1,006	-360	-989	-1,815	-739	-4	1,628	1,367
Chile	13	12	15	16	11	13	11	16	9	14	10	9	7	5	5
China	-66	1,402	894	571	351	1,342	2,314	4,009	7,078	5,883	5,716	9,179	9,904	7,980	15,003
Czech Republic	14	-13	57	56	77	53	53	67	55	5	99	89	73	73	63
Finland	-2,328	-2,538	-3,058	-3,315	-1,574	-1,661	-3,176	-2,845	-2,655	-5,392	-1,744	-4,367	-2,379	-2,722	-1,083
France	730	914	909	1,222	995	1,097	1,212	1,259	1,342	1,280	1,506	1,346	1,661	1,112	1,328
Germany	749	1,061	1,057	795	1,408	1,033	1,526	1,729	1,806	1,783	1,446	2,093	2,570	1,401	1,942
Hungary	13	13	17	16	19	16	16	18	25	15	17	18	15	13	15
India	298	314	368	414	456	425	493	580	569	670	744	934	975	734	1,021
Indonesia	32	81	86	97	52	100	131	141	130	124	125	100	107	65	74
Italy	910	973	1,190	1,152	1,243	1,077	1,167	1,237	1,232	1,089	1,007	1,142	1,201	901	654
Japan	5,197	5,453	7,042	7,197	7,120	9,013	11,489	8,472	9,960	13,289	15,583	12,617	12,334	9,503	11,885
Malaysia	135	266	162	68	329	735	656	616	2,362	3,469	1,610	2,142	4,603	1,509	-255
Mexico	146	133	185	216	232	214	225	217	188	194	143	178	199	129	132
Netherlands	122	247	-538	-206	72	307	-1,352	-1,636	-663	-2,084	-536	228	865	-97	164

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Norway	-2,146	-2,387	-2,659	-2,918	-3,299	-3,795	-3,228	-2,935	-3,111	-3,648	-3,627	-4,128	-4,031	-2,540	-2,637
Poland	-21	67	62	74	67	55	74	52	73	63	63	71	43	46	50
Portugal	29	33	39	38	38	35	34	31	33	40	37	32	39	25	23
Russia	3,000	3,500	1,039	-499	271	-691	-1,586	850	1,269	905	465	2,397	753	2,024	2,070
South Africa	370	290	350	465	435	450	606	684	552	-146	-204	-1,126	-387	-120	-358
South Korea	756	891	697	720	658	1,033	1,491	1,261	1,947	2,635	3,494	3,530	5,030	4,200	756
Spain	351	450	565	714	887	898	1,144	1,205	1,263	1,368	1,076	1,070	1,124	730	105
Sweden	35	-12	582	699	783	502	616	699	430	469	501	509	610	421	486
Thailand	37	39	90	157	139	204	313	228	253	192	192	250	311	207	223
Turkey	50	69	93	107	93	95	120	104	143	216	218	232	250	201	214
United Kingdom	737	660	945	972	645	1,348	750	875	1,394	700	865	1,408	1,715	1,217	1,229
USA	4,169	4,640	4,946	5,776	5,469	6,465	5,892	6,092	5,254	4,311	4,964	6,333	6,725	5,336	5,718
Venezuela	24	24	22	24	8	20	19	16	11	9	31	49	34	22	17
Total	**18,221**	**22,086**	**20,382**	**18,580**	**20,292**	**24,506**	**26,832**	**28,792**	**36,815**	**30,713**	**35,329**	**40,223**	**44,427**	**34,781**	**42,111**

Table 42 – Cobalt apparent consumption

Source: Own estimation

9.3.6 Vanadium

HS code	Description	Vanadium content estimation	Remark
720292	Ferro-vanadium	Based on specific trade value in US dollars per kilogram relative to ferro-vanadium price	Compare chapter 4.2
282530	Vanadium oxides and hydroxides	Based on specific trade value in US dollars per kilogram relative to vanadium pentoxide price	Compare chapter 4.2
262050	Ash or residues containing mainly vanadium	Based on ratio of specific trade value relative to specific trade value of vanadium oxides and hydroxides in US dollars per kilogram multiplied with the calculated vanadium content in vanadium oxides and hydroxides	Compare chapter 4.2

HS code	Description	Vanadium content estimation	Remark
811240	Vanadium, articles thereof, waste or scrap/powders	Assumed same content as ferro-niobium trade	Compare chapter 4.2

Table 43 – Overview vanadium content estimation

Source: Own illustration

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Argentina	44	121	80	135	56	150	73	116	131	136	98	71	116	184	138
Australia	184	188	196	227	233	249	1,643	876	-1,601	-347	267	323	264	171	127
Austria	-3,050	-2,365	-3,722	-3,587	-4,810	-3,938	-3,559	-4,085	-3,365	-3,355	-2,951	-3,321	-4,414	-5,516	-4,096
Belgium	0	5,042	3,219	3,072	1,609	1,912	2,587	2,097	2,400	35	-3	19	441	431	338
Brazil	485	736	737	517	902	579	749	826	766	1,105	718	802	1,190	1,390	1,111
Canada	737	2,001	1,732	2,012	1,774	1,357	891	697	715	817	914	809	874	714	1,096
Chile	13	0	4	2	3	10	12	-0	0	0	16	2	13	4	3
China	3,756	7,581	8,569	8,404	8,225	4,387	4,485	6,909	9,136	7,748	14,432	9,514	7,508	3,377	6,738
Czech Rep.	-527	-1,791	203	-27	-777	2,410	2,669	3,024	1,532	2,223	2,200	1,488	2,451	1,744	2,622
Finland	139	135	187	101	180	150	109	162	160	179	136	166	186	234	192
France	684	760	973	1,597	1,521	1,023	956	1,033	1,010	1,034	800	1,021	1,579	1,707	1,366
Germany	3,275	2,488	2,404	2,965	3,899	3,007	3,125	3,896	2,644	3,238	1,636	2,089	3,427	3,155	2,713
Hungary	0	259	247	218	185	0	46	27	54	42	38	0	33	21	19
India	28	12	23	50	171	120	364	193	184	234	285	127	464	346	199
Indonesia	210	130	178	215	17	93	100	70	-342	25	35	116	120	41	0
Italy	1,257	1,513	1,388	1,413	1,292	1,037	-914	836	434	1,132	1,284	1,124	1,455	1,717	1,352
Japan	2,962	5,879	5,871	6,529	7,169	5,567	6,659	6,125	6,257	6,951	5,581	6,317	6,621	5,816	5,964
Malaysia	398	232	226	205	41	108	269	228	378	172	328	101	138	237	0
Mexico	191	690	303	546	373	493	534	398	448	418	479	521	568	281	583
Netherlands	-21	622	114	-275	1,639	362	1,200	271	2,070	965	850	521	662	579	52
Norway	21	33	20	15	17	40	59	50	50	53	39	33	48	23	19
Poland	146	315	217	197	220	254	363	286	240	161	289	204	347	282	208
Portugal	6	9	6	2	1	4	3	7	40	18	0	0	5	18	2

Metric tons	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Russia	6,246	8,175	8,004	7,030	7,205	2,222	704	683	1,211	1,963	6,263	10,390	10,461	10,136	9,831
South Africa	10,001	5,802	6,323	7,627	11,382	6,974	9,322	10,868	17,858	14,275	10,253	17,210	11,898	13,001	12,331
South Korea	805	1,583	1,913	2,499	2,283	2,821	2,671	2,294	2,442	2,700	1,949	2,380	3,399	6,900	3,545
Spain	505	468	596	193	110	438	370	657	538	519	644	428	509	715	472
Sweden	749	668	588	561	1,108	818	681	656	481	837	828	619	845	615	518
Thailand	114	162	174	37	17	33	37	30	34	33	43	42	53	-61	68
Turkey	135	110	84	159	119	95	131	184	591	374	173	132	308	327	291
Ukraine	n/a	n/a	709	243	459	388	848	818	709	1,443	1,388	1,259	1,521	1,613	1,087
United Kingdom	380	457	539	523	-142	317	-810	114	137	12	82	805	853	160	37
USA	318	2,579	460	2,031	2,047	1,950	2,892	2,575	1,689	230	1,459	2,424	3,364	3,366	5,077
Venezuela	47	120	76	30	161	98	201	148	143	208	90	207	262	143	0
Total	**30,237**	**44,712**	**42,642**	**45,464**	**48,690**	**35,529**	**39,468**	**43,068**	**49,174**	**45,575**	**50,642**	**57,941**	**57,569**	**53,872**	**54,005**

Table 44 – Vanadium apparent consumption

Source: Own estimation

9.4 Chinese export tariffs

Metal group	Metal	HS code	Description	Export tariff				
				2005	2006	2007	2008	2009
Refractory metals	Chromium	26100000	Chrome ores and concentrates	0%	0%	10%	15%	15%
		81122100	Unwrought chromium	0%	0%	15%	15%	15%
		81122200	Chromium scrap	0%	0%	15%	15%	15%
		72024100	Ferro-chrome (C 4% min)	0%	5%	10%	20%	20%

Metal group	Metal	HS code	Description	Export tariff				
				2005	2006	2007	2008	2009
		72024900	Ferro-chrome (C 4% max)	0%	5%	10%	20%	20%
		72025000	Silico-chrome	0%	0%	10%	20%	20%
	Manganese	26020000	Manganese ores and concentrates	0%	0%	0%	15%	15%
		81110010	Unwrought manganese	0%	0%	15%	20%	20%
		72023000	Silico-manganese	0%	5%	10%	20%	20%
		72021100	Ferro-manganese	0%	5%	10%	20%	20%
	Molybdenum	26139000	Molybdenum ores and concentrates	0%	0%	10%	15%	15%
		26131000	Roasted molybdenum ores and concentrates	0%	0%	10%	15%	15%
		81021000	Molybdenum powder	0%	0%	15%	15%	10%
		81029400	Unwrought molybdenum	0%	0%	15%	15%	15%
		81029700	Molybdenum scrap	0%	0%	15%	15%	15%
		28257000	Molybdenum oxides and hydrates	0%	0%	0%	15%	15%
		28417010	Ammonium molybdate	0%	0%	0%	15%	10%
		72027000	Ferro-molybdenum	0%	0%	10%	20%	20%
	Niobium	72029300	Ferro-niobium	0%	0%	10%	20%	20%
	Vanadium	28253010	Vanadium pentoxide	0%	0%	0%	5%	5%
		72029290	Ferro-vanadium (V max 75%)	0%	0%	10%	20%	20%

Metal group	Metal	HS code	Description	Export tariff				
				2005	2006	2007	2008	2009
		72029210	Ferro-vanadium (V min 75%)	0%	0%	10%	0%	0%
	Cobalt	26050000	Cobalt ores and concentrates	0%	0%	0%	15%	15%
Non-ferrous base metals	Aluminum	26060000	Aluminum ores and concentrates	0%	0%	0%	15%	15%
		76011010	Unwrought aluminium,containing by weight 99.95% or more of aluminium	0%	0%	0%	15%	
		76011090	Unwrought aluminium,other	0%	0%	15%	15%	
		76012000	Unwrought aluminium,aluminium alloys	0%	0%	0%	15%	
	Copper	26030000	Copper ores and concentrates	0%	0%	0%	10%	10%
		74031111	refined copper and copper alloys, unwrought, containing by weight more than 99.9935% of copper	0%	0%	10%	5%	
	Lead	78011000	unwrought lead, refined lead	0%	0%	10%	10%	
	Tin	26090000	Tin ores and concentrates	0%	20%	20%	20%	20%
	Zinc	26080000	zinc ores and concentrates	0%	0%	0%	0%	
		79011190	unwrought zinc, other	0%	0%	5%	5%	
		79012000	unwrought zinc, zinc alloys	0%	0%	0%	0%	

Table 45 – Chinese export tariffs

Source: China Customs 2005; China Customs 2006; China Customs 2007; China Customs 2008; China Customs 2009;

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