Root Cause Analysis of Price Behaviour of Copper and Copper Market Volatility

by

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ABSTRACT

A decade of extremely high and volatile copper prices has disturbed industries and raised the need for an extensive understanding of current predictors by means of indicators, signals, events and developments concerning the copper market. The goal of this research is to find a suitable method to prioritise events (including developments) on their impact on the copper market and to identify the root causes for these impacts. In order to asses future scenarios, this study can be used to identify predictors, which will improve the understanding of the dynamics of the copper market.

In this research a large set of open data sources was analysed. This data was retrieved from USGS, World Bank, company reports, commodity reports and scientific researches. Furthermore, 29 case studies were analysed on various topics. These case studies consist of time series analyses, logical reasonings and assessments on future potential impacts. By interviewing external experts, different perspectives on the copper market were identified.

Events were prioritized on the impact each caused on the copper market. To quantify this impact, a new indicator was developed. This indicator was derived from a surprise component, which was defined from literature. The surprise component indicates the effect of economic news on the commodity markets. The surprise component includes the market uncertainty at a specific moment in time and the deviation of the actual price from the expected price. The general idea of the developed indicator is to include the duration of an event. This is realized by a summation of the consecutive surprise components within this duration. Because the deviations are generally larger for long term events, a linear bias occurs. This bias was eliminated making the newly developed indicator also suitable for expressing the impact of long term events.

This indicator enabled the first step in the root cause analysis and identified the events which caused the most impact, such as major wars, economic booms and technological developments. However, other types of events have caused more severe price shocks (a deviation from the expected price which is more than the standard deviation). The cyclical nature of the market, financial crises and a rapidly transforming climate for investment in a supply region are considered to be events causing the most severe price shocks.

To identify the root causes for the events' and developments' impacts, associated indicators and signals were determined. By means of the case studies, those indicators and signals could be objectively valued. From the identified root causes, awarenesses of additional complexity are revealed. For example, it is assumed that economic growth in China will affect the copper market significantly. However, due to China's current status in several economic indicators, the significance of this impact is questioned. Economic growth in underdeveloped regions, such as India or Sub-Saharan Africa, will affect the copper market more significantly. Another key example is the recycling industry, which is much less matured as common statements make one believe, since the recycling effi-

ciency continues to stay below 35%. The case studies verified the indicators and signals and have provided information on the likelihood, future progress and impact of events affecting the copper industry.

In order to assess the current relevance and significance of the studied indicators and signals, each was brought into today's perspective. It is presumed that certain indicators and signals might have changed in significance. First; the oil price, this study proves that pre-2000 events on the oil market only caused minor impacts on the copper markets. However, causal relations were deduced between the recent oil peak and the high marginal costs of copper. This suggests a possible increase in relevance of the oil market affecting the copper market. Secondly, the newly developed incentive for a transition to a sustainable society with an efficient use of energy. This will require appliances with a high content of copper. Massive embracing of these new appliances could boost the demand for copper. Lastly, the impact of an increase in demand due to wars. While the copper market is growing rapidly, magnitude of war would need to increase to affect the market with the same impact. The assessments for today's significances show that new drivers will enter the market and old drivers could reduce.

This study revealed that the copper market was subject to both random and non random events. Pattern recognition does not seem a suitable tool to provide an understanding the behaviour of the copper price, but comprehending the root causes and the consequences of the events is of use. This study defined a set of indicators and signals (e.g. U.S. dollar currency index, discount rate and gold price) which stakeholders can use to optimize risk analyses. Monitoring and stimulating the development of alternative sources for copper, including recycling and deep sea mining, will enable the possibility to bypass risks. Lastly, indicators and signals, related to the sustainable energy transition, economy, company strategies and new innovations in processing and extraction technologies, will indicate how the balance in supply and demand will develop.

This study improves the understanding of current dynamics of the copper market and the identified set of predictors will benefit stakeholders to improve their strategies. Updating this study will ensure industries are prepared for future market fluctuations.

CONTENTS

DEFINITIONS

In this thesis, terms are often used which can be interpreted on several ways or could cause confusion. To clarify this, the definitions of recurring terms in this text, are given below. Terms, which are more specifically used within one subject, will be clarified (again) in the specific section.

- **Development**: The process of an economic, social or technological transformation, that arises from complex factors and their interactions (Business Dictionary 2016*a*). Often the transformation is slow and takes a long time span to occur.
- **Driver**: "The driver is the element that has a major or critical effect on the associated elements, such as events and developments, or the entire system, like the copper market" (Business Dictionary 2016*b*).
- **Early Warning Indicators**: An indicator which shows an alteration preceding a change in the concerning system.
- **Event**: A situation of which the precise time and location can be determined. The event can be dependent and independent from other events or developments.
- **Financial Crises**: A rapid fall of the value of financial institutions or assets. It is often accompanied by panic, run on banks and high uncertainties (Investopedia 2016*b*). Historical crises are marked in this thesis, but are not further discussed in detail.
- **Flotation**: A process wherein hydrophobic and hydrophilic minerals are separated from each other. This technique is widely popular and frequently used. It is more discussed in section 7.4.3.2.
- **Gross Domestic Product (GDP)**: Is the total value of all domestically finished goods and services. It is often used as an indicator for the economy (Investopedia 2016*c*).
- **Indicator**: "Measured variable used as a representation of an associated (but non-measured or non-measurable) factor or quantity" (Business Dictionary 2016*c*).
- **Marginal Costs**: The costs of producing one additional item can be calculated by dividing the "change in total production costs" by the "change in total quantity produced". Generally it is close to the costs of production. However, if a company approaches its maximum capacity, it needs to invest in new facilities. Those costs are included in marginal costs and will cause an increas (Investopedia 2016*e*).
- **Old and New Scrap**: New scrap exits consists of scrap which is produced during the manufacturing of products, but ended up in failed products or as residue. While old scrap is the copper retrieved from products that reached their end-of-life (USGS 2010*a*).
- **Porphyry Copper Deposits**: Formed by a repeating process in which rocks, above an sub volcanic intrusion, fracture and are filled by the precipitation of copper by aqueous fluids, released by the intrusion (J.H.L. Voncken 2011). Porphyry copper deposits are characteristically large low ore grade deposits, which can be pro-

cessed by flotation technology.

- **Postwar Economic Boom**: After World War II, the economies of the OECD members grew continually for two decades. An average growth of 4% in the 1950's and near 5% in the succeeding decade. After a few big events in the early seventies, such as the oil-crisis and the 1973-1975 recession, the grew fell back to an average of 2 to 3%. This is considered the end of the postwar economic boom. (Marglin & Schor 1990, The World Bank 2014*a*).
- **Predictors**: A name of a group of parameters which provide information about the market. The group consist of indicators, signals, events and developments.
- **Production/Operating Costs**: All costs related to the production of one item. This not only includes labour, raw materials and consumables, but as well taxes for governments and royalties on extracted natural resources. (Investopedia 2016*g*).
- **Purchasing power parity (PPP)**: An adjustment, to compensate for the purchasing power, which has to be made on the exchange rate. A foreign nation's currency is exchanged to an international dollar. This is a factor which is specific for the cited nation. For one international dollar, a comparable amount of goods and services can be bought as for one U.S. dollar. The ratio between the international dollar and the U.S. dollar is the PPP for the specific nation (Investopedia 2016*h*, The World Bank 2016). A simplified version of the PPP is the 'Big Mac Index'. In this index all global prices for a Big Mac are compared in U.S. dollars. Exchanged in U.S. dollars, a Big Mac in Norway, does not cost necessarily the same in dollars (Economist 2011).
- **Recycling Efficiency**: The part of all available scrap, ready to be recovered and reused, which is actually recovered and reused (USGS 2010*a*).
- **Sediment-Hosted Copper Deposits**: Hydrothermal fluids dissolve copper and let it precipitate on a particular distance of the source. The ore grades are generally of higher grade as the ones in a porphyry deposit (J.H.L. Voncken 2011, USGS 2009). This ore is generally processed by solvent extraction.
- **Signal**: "An action or movement that gives informations and could purpose as a message or warning (Cambridge Dictionary 2016). Just like indicators, do signals show the status of an event or development and do they help to determine the relevance of an event or development.
- **Solvent Extraction and Electrowinning**: Copper is (slowly) dissolved by acid fluids, which flow through a heap or crushed material. After some purification steps, copper is extracted out of the fluids by an electrolytic procedure (Sole & Tinkler 2014).

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INTRODUCTION

1.1. INTRODUCTION

The copper market is a dynamic and complex market, which is subject to both random and expected events. After a decades long period, in which the copper market behaved relatively stable, the last decade was defined for a rapid increase of the demand for copper. This resulted in a period of extremely high prices. After its peak in 2011, it almost ended as abruptly as it started. The described trends are visualized in figure 1.1.
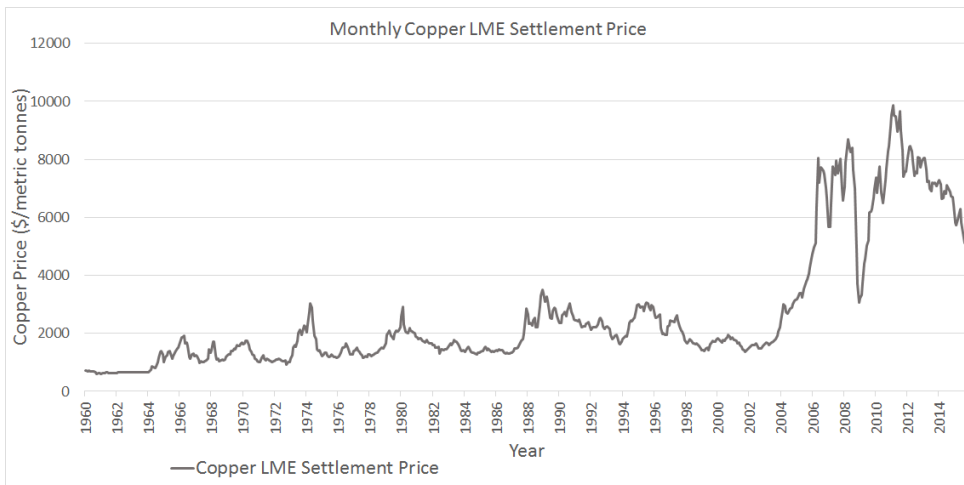
Figure 1.1: The monthly copper LME settlement price (YCharts.com 2016).

The sudden changes of behaviour of the copper market set a scenario, for which companies and governments were unprepared. Companies worried about mineral scarcity and others were unprepared for new phenomenons, such as copper theft. The scenario

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resulted in an increased attention towards the copper market by e.g. consultancies, think tanks and research institutes. All trying to answer the question of what the actual market's current drivers are. Furthermore, they want to define strategies to prepare for probable future scenarios by understanding the predictors in the copper market.

This thesis follows up clear strategies, defined by The Hague Centre for Strategic Studies (2012) in the study "Futures for Copper". This study provides a first set of important drivers in the copper market. Furthermore, it states that actors in demand and supply need to be able to react quickly to new situations and are able to adapt to, and compete with sudden developments in the market by means of substituting and recycling. It also states the possibility of other, yet undefined, scenarios. This thesis will study the developments in the copper market and in particular from the perspective of the largest supplier of copper, the extracting industry. This thesis will propose an improved understanding of the copper market, by adding and validating a wider range of predictors

An important underlying thought of this thesis is the assumption that the copper market has chaotic characteristics and is subject to both random and non-random events (C Tapia Cortez & Sammut 2015). The focus of both, this thesis and the proposed method, will principally be based on events and developments initially stated by Edelstein (1998, 2010). Furthermore, this thesis will emphasize the interdependencies, the complexity and actual causalities between events and developments and the copper market.

1.2. OBJECTIVE

This study aims to show that the understanding of events and developments are most important in order to understand the fluctuations on the copper market. This is done by meeting the following goal:

- Identification of indicators, signals, events and developments which improve the understanding of the dynamics of the copper market.

The following outline is set for this study:

1. Proposing a method to define events and developments, which have historically affected the copper market most.
2. Verify the significance and the causal relation of the method's outcomes with the copper market for both, past and present.
3. Deliver an improved understanding of the current dynamics of the copper market, by means of a extensive research in a wide range of aspects.

2

FOUNDATION OF DATA

2.1. DATA

2.1.1. TIME SERIES

The copper market and its movements can be considered as a very complex, non-linear system and is influenced by numerous events and developments. To go further in this research, it is essential to get a better understanding of the behaviour of the copper market. To obtain this, a time series analysis was done. The foundation of this analysis is the monthly copper LME settlement price (YCharts.com 2016), which covers the period of 1960-2015. This time-series is shown in figure 2.1.
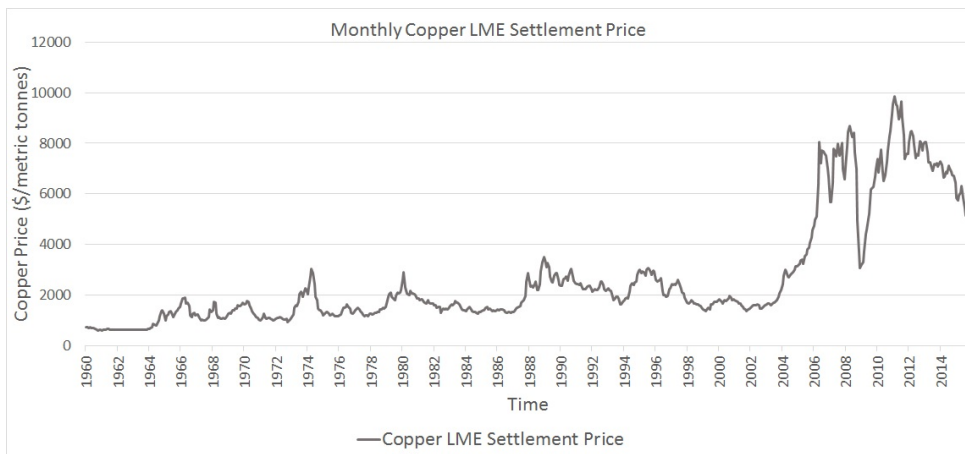
Figure 2.1: The monthly copper LME settlement price (YCharts.com 2016).

2.1.2. EVENTS AND DEVELOPMENTS

The result shows that the copper market is quite active. All the peaks and troughs can be explained by events and developments occurring in that period of time. The United States Geological Survey published in 1998 and 2010 a list of "significant events, that affected the copper price". This list is shown in the appendix in table A1(Edelstein 1998, 2010). Some of those events are combined into one big development. Furthermore is the development of technology included in this research, which is not mentioned by USGS.

CATEGORIZING

Nine main categories are determined. All sixty events can be subdivided into these categories. These categories will be tested and ranked on the influence they have on the market. The categories are:

Accessibility
Events which affect the accessibility of a foreign nation with a lot of copper reserves by causing restrictions or disruptions in the copper supply.

Demand
The global or regional increase or decrease of consumption. Related to the cyclic nature of commodity markets, wherein under- and oversupply are alternating each other due to delays in response time of the effect of cancelled or new investments (Rosen et al. 1993).

Dependent
Those are directly linked to earlier events or are already mentioned. Those events are ignored in the impact assessment.

Economic Boom
Not a rising demand or a simple economic growth, but a major economic growth which addresses a big part of the world population.

Economic Crises
(Rapid) decline of the global or a regional economy.

Supplemental Information
Mentioned events, which are not recognizable in the time-series. This could be for example, due to a balance with an event with the opposite effect. Because of the disability to measure the impact of these events, these are ignored in this research.

Special Events
Solitary events with rare precedents or recurrence. Events in this category do not fit in other categories.

Technology
Development in mining or processing technology. Related to the primary/secondary copper. This category has no relation with the copper use in high-tech products.

War/Conflicts
Increase in copper demand, due to wars or conflicts.

Appendix, table A2 shows how the events, mentioned by the USGS, are subdivided into these nine categories.

2.2. DEMAND AND SUPPLY

2.2.1. SUPPLY

GEOLOGY

Copper ore deposits appear in many forms. The two most occurring forms are the Porphyry deposits and the Sediment-Hosted copper deposits which represent respectively two thirds and 25% of all mined copper deposits (USGS 2009).

Porphyry Copper Deposits   Porphyry copper deposits are characteristically large low ore grade deposits. A famous example is Chuquicamata in Chile, which contains 17,1 billion tons of ore, grading 0,65% Cu and containing in total 111,15Mt of copper (USGS 2005). The processing is done by flotation techniques, which enables the possibility to extract ore with such a low grades of copper. This technique is widely popular and frequently used. It is discussed further in section 7.4.3.2.

Sediment-Hosted Copper Deposits   Hydrothermal fluids dissolve copper and let it precipitate on a particular distance of the source. The ore grades are generally of higher grade than a porphyry deposit (J.H.L. Voncken 2011, USGS 2009). An often used technique is the solvent extraction and electrowinning. Copper is (slowly) dissolved by acid fluids, which flow through a heap or crushed material. After some purification steps, copper is extracted out of the fluids by an electrolytic procedure (Sole & Tinkler 2014). Last mentioned steps are also applied in the flotation technology.

Both types of deposits account for 90-95% of mined copper deposits worldwide. In 2005 there were 381 porphyry deposits, containing 1336 Mt copper (USGS 2005), and 141 sediment-hosted copper deposits in 2003, containing 383 Mt of copper (USGS 2007). Figure 2.2 shows how those deposits are distributed over the world (USGS 2009).

The grades and tonnages of all porphyry and sediment-hosted copper deposits, reported in respectively 2005 and 2003, are shown in figure 2.3, 2.4 and 2.6. Afterwards, both deposit types are compared on basis of the copper content.

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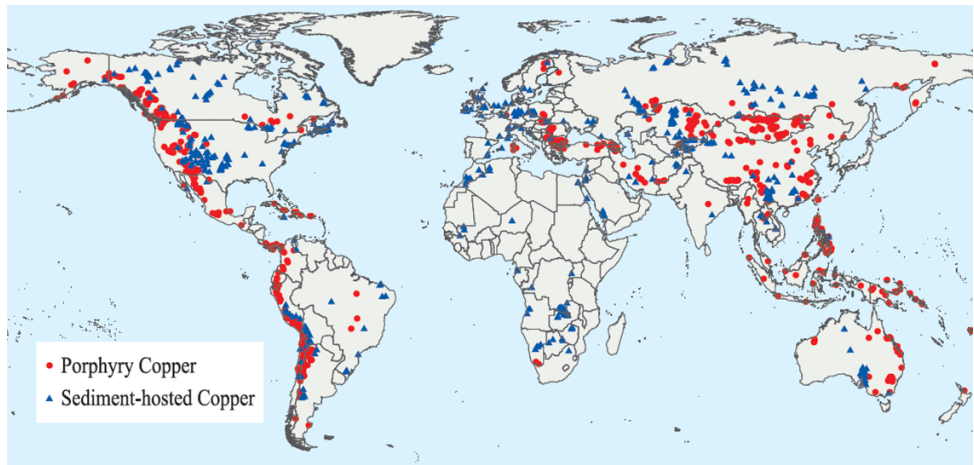
Figure 2.2: A map of the world, in which both the porphyry and sediment-hosted copper deposits are pointed. A high concentration of porphyry deposits can be identified on the west coast of the South- and North American continents. The sediment-hosted copper deposits are in smaller amounts and are more spread out of the world (USGS 2009).
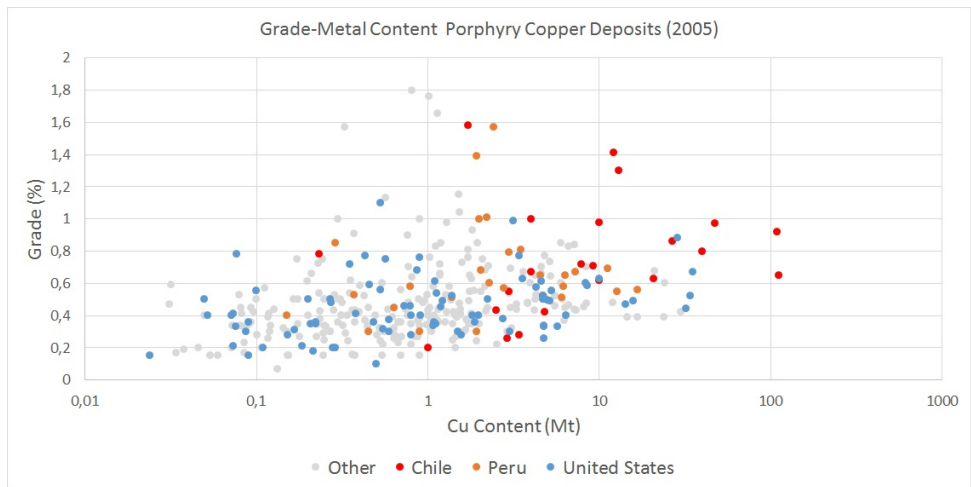
Figure 2.3: A plot of the grades and the corresponding copper content for 381 porphyry copper deposits. Porphyry deposits in Chile and Peru have generally high copper content and also have relatively high grades of copper. Deposits in the United States vary more in both grades and in total copper content (USGS 2005).
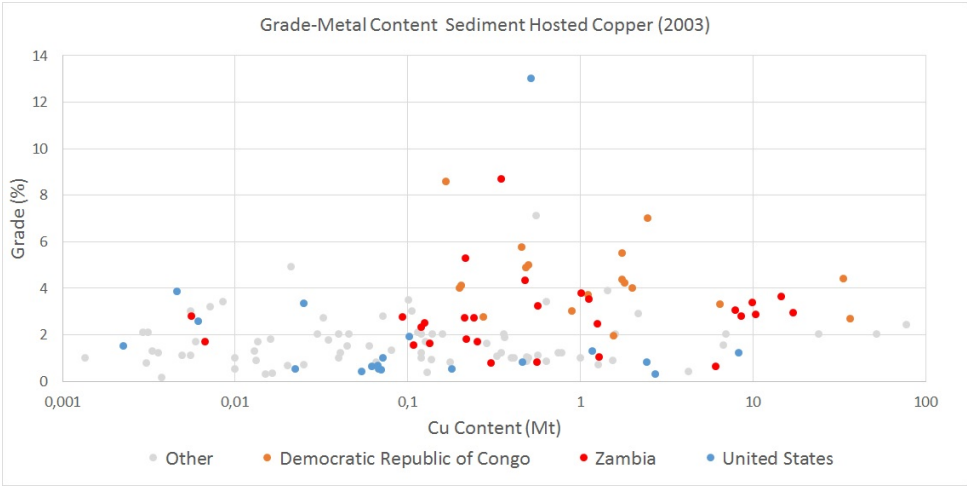
Figure 2.4: A plot of the grades and the corresponding copper content for 141 sediment-hosted copper deposits. Sediment-hosted copper deposits in the Copperbelt (Democratic Republic of Congo and Zambia) have generally high copper contents and relatively high grades of copper. Deposits in the United States vary more in both grades and in total copper content (USGS 2007).
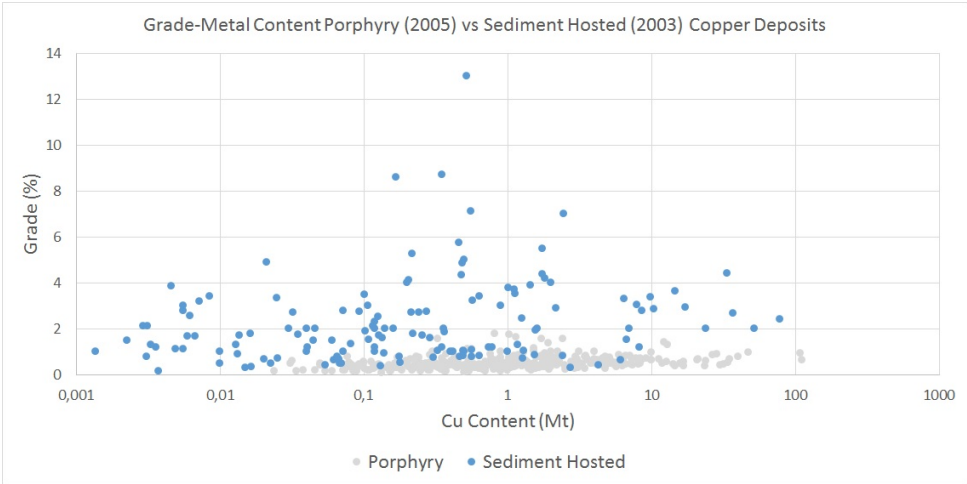
Figure 2.5: A plot of the grades and the corresponding copper content for 141 sediment-hosted copper deposits and for 381 porphyry copper deposits. What is clearly shown, is the high grades of sediment-hosted copper deposits, compared to the low grades of porphyry deposits. Concerning the total copper content, both types are varying in similar ranges (USGS 2005, 2007).

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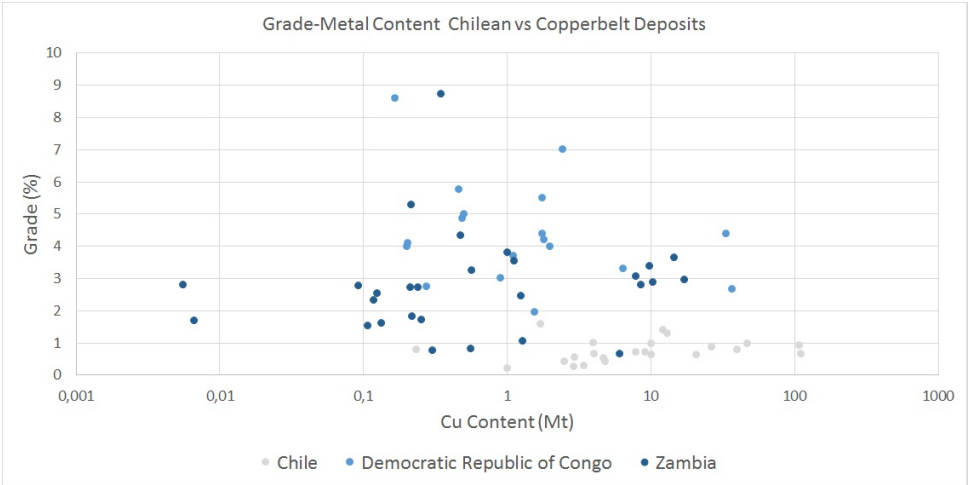
Figure 2.6: A plot of the grades and the corresponding Cu content for 28 Zambian, 18 Congolese and 23 Chilean copper deposits. The total copper content of all the deposits combined within Zambia, Congo and Chile, is respectively 83Mt, 92Mt and 449Mt (USGS 2005, 2007).
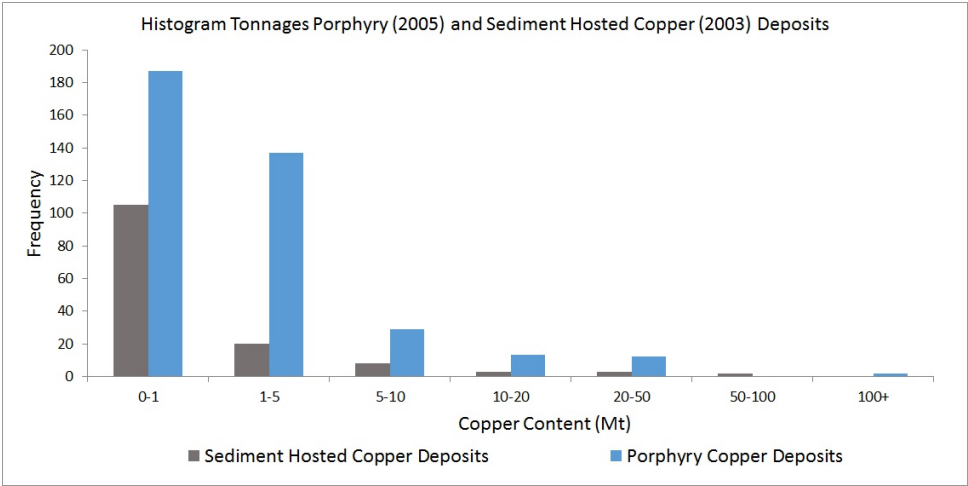
Figure 2.7: Both types of deposits are ranked on copper content and the frequency of deposits with different amounts of copper content is shown (USGS 2005, 2007).
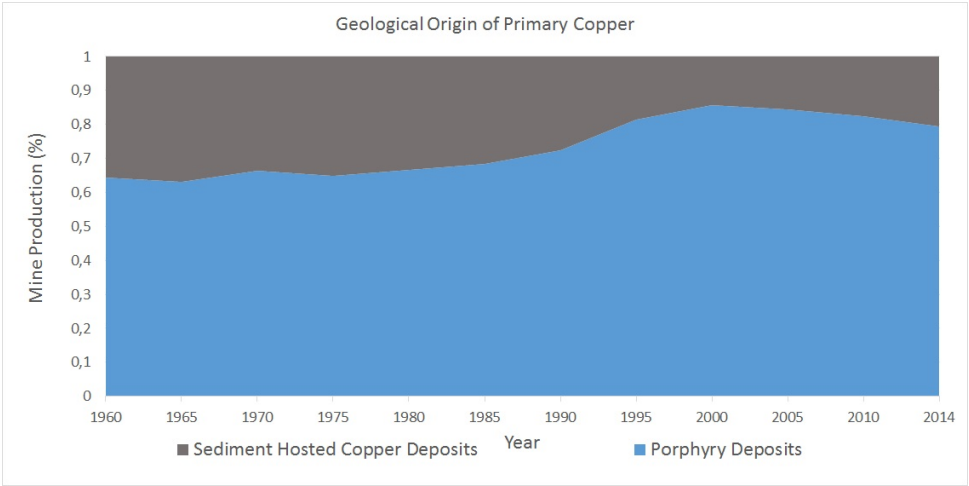
Figure 2.8: A time series of the geological origin of primary copper. Deposit types, other than porphyry and sediment-hosted copper deposits, are ignored, due to their small share in global production. An assessment is done for each of the major producing nations, in which the ratio of mined porphyry and sediment-hosted copper deposit is determined. With this information, a geological origin of primary copper over time can be determined (USGS 2005, 2007, USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013).

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These figures will be used in the argumentation to emphasize the importance of characteristics, like grade and tonnages, in the global copper market. Those 'copper nations' are the nations who lead in the production of copper and are determined next.

PRODUCTION

About 50% of the primary copper production is done by twenty mines (figure 2.9(ICSG 2014, Rio Tinto 2016*a*, Mining.com 2015*c*, Freeport McMoRan 2015). Same accounts for the producers, in which 10 companies produce almost 50% of all primary copper. The share of production by companies and nations are visualized by table 2.1 and figures 2.10 to 2.12.

Next, is the mine production shown over time and broken down to the origin of the copper (figure 2.10). It shows that the origin of copper is dynamic and varies over time. This becomes more clear in figure 2.11, where the origins are presented as share of the total. The figures and the accompanying dynamics, will be discussed and used in the argumentation of future case studies.

In the last figure of this section, the reported copper reserves are shown. Nowadays, there are more copper reserves, than in 1995. Also here, a dynamic movement is visible.
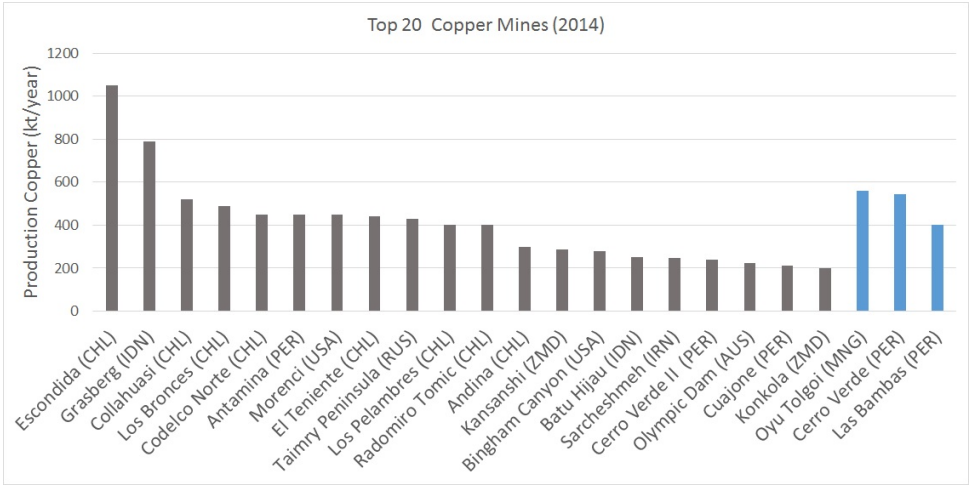
Figure 2.9: About 50% of the copper production is done by twenty mines. Some new mines coming on-line soon are coloured blue (ICSG 2014, Rio Tinto 2016*a*, Mining.com 2015*c*, Freeport McMoRan 2015).

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Table 2.1: The top-10 copper producing companies. Those values can differ from company reports. Combined, those 10 producing companies produce 50% of global copper production (GFMS 2013, 2014, 2015, 2016).

Company	2015 Production (kt)
Codelco	1.893
Freeport-McMoRan	1.547
Glencore	1.259
BHP Billiton	1.178
Southern Copper	745
KGHM Polska Miedz	562
Rio Tinto PLC	555
Anglo American	472
Antofagasta	400
First Quantum Minerals	366

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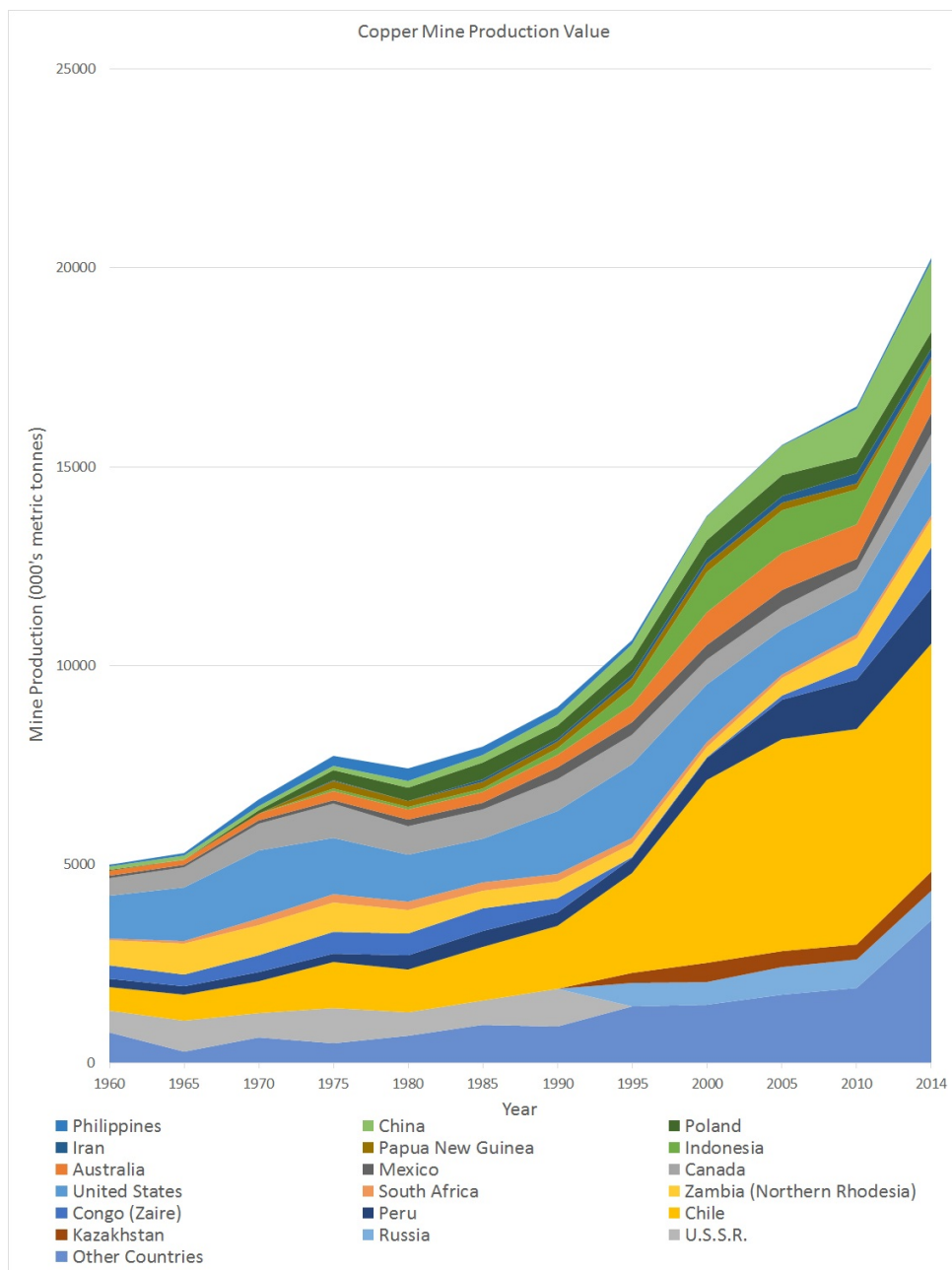
Figure 2.10: A time series of the production in absolute figures for the main producing nations is shown. A clear rise in production is visible (USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013).
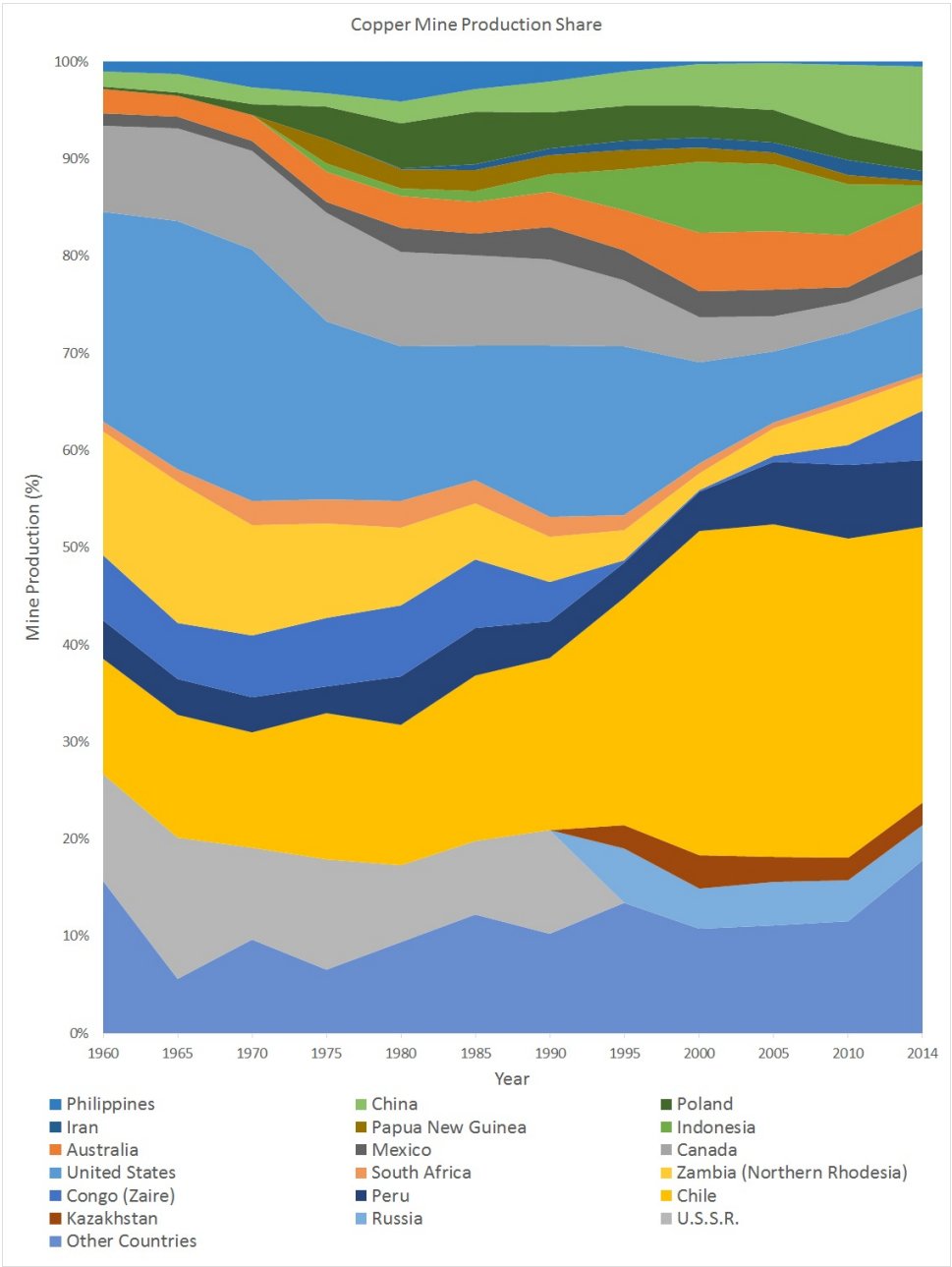
Figure 2.11: A time series of the production in relative figures for the main producing nations is shown. Visible is that the Unites States lost its status as number one producer to Chile during the 80's and 90's. Furthermore was the Copperbelt a significant producer during the 60's until the early 80's and after a period of minor production, the nation's copper industries are picking up again (USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013).

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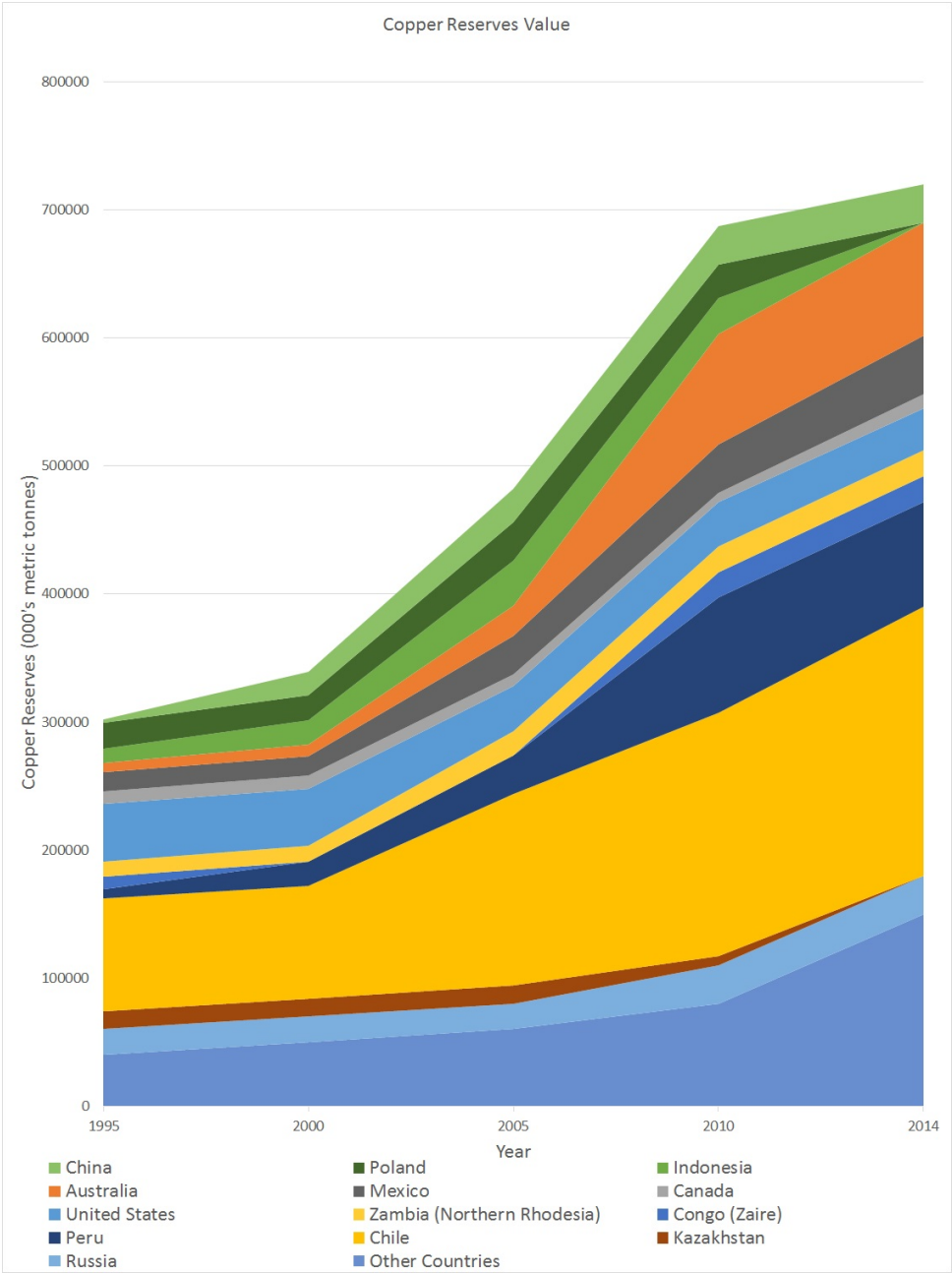
Figure 2.12: A time series of the reserves in absolute figures for the main producing nations is shown. A clear rise in reported reserves is visible (USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013).

2.2.2. DEMAND

COPPER USE

Consumption is a recurring theme on the list of significant events (Table A1). This thesis will show how important this theme is and how future consumption may affect the market. A basic understanding of the uses of copper is therefore essential. This is done by explaining how copper is used in the world. Those end-uses of copper can be subdivided into five categories. These, together with some main examples, are (GFMS 2013, 2014, 2015, 2016):

- Building construction: building wire, plumbing & heating, air conditioning & commercial refrigeration, builders hardware and architectural.

- Electrical and electronic products: power utilities, telecommunications, business electronics and lighting & wiring devices. Specific examples are computers, cords, plugs, connectors, light bulbs, coffee makers and blenders.

- Industrial machinery and equipment: in-plant equipment, industrial valves & fittings, non-electrical instruments and heat exchangers.

- Transportation equipment: auto-mobile, trucks & buses, rail-road, marine, aircraft & aerospace. Specific examples are electronics, wire harnesses and copper magnet wires and heat exchangers (Center for Automotive Research 2006, Copper Development Association Inc. 1998, Finnradiator 2016).

- Consumer and general products: appliances, cord sets, military ordnance, consumer electronics, fasteners & closures. Specific examples are televisions, washing machines and bullets.

CONSUMPTION PATTERNS

Furthermore, GFMS has reported how the consumption is distributed over the five categories. This is shown in figure 2.13.

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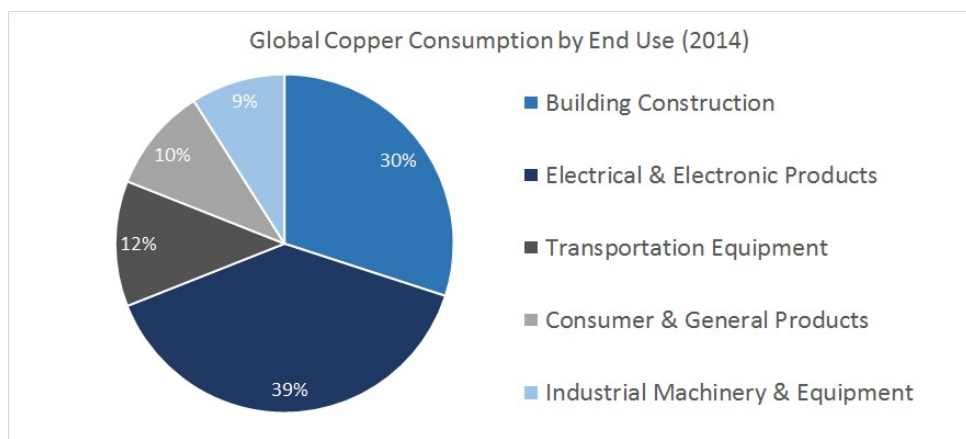
Figure 2.13: Global Copper Consumption by End Use (GFMS 2013, 2014, 2015, 2016).
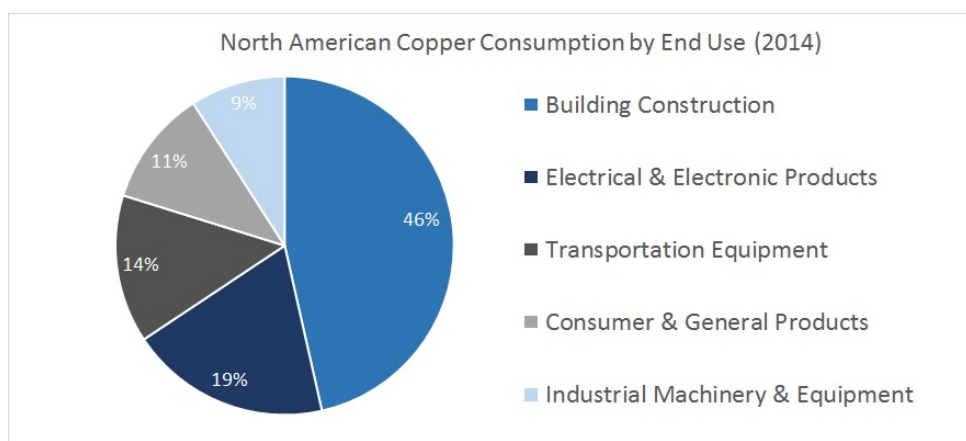
Figure 2.14: North American Copper Consumption by End Use (GFMS 2013, 2014, 2015, 2016). The high share of building construction could be explained by a steady U.S. recovery of the construction industry, since the 2008 financial crisis. The share of transportation equipment is possibly an indicator for the car popularity in the states.
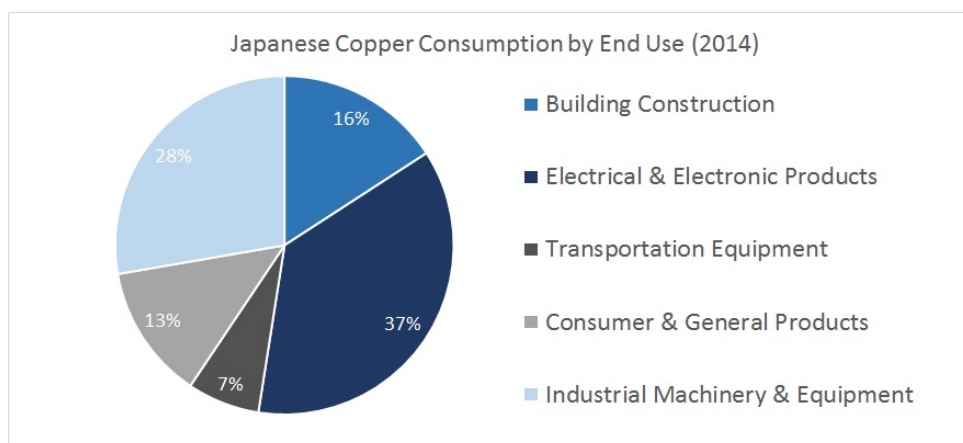
Figure 2.15: Japanese Copper Consumption by End Use (GFMS 2013, 2014, 2015, 2016). The Japanese historical focus on the manufacturing of electrical and electronic products can still be recognized in the high share of 'electrical & electronic products' (BBC 2013).

The figures presented in figure 2.13 are globally. Those consumption patterns are not the same throughout the world and differ for each region. Figures 2.14 and 2.15 show a quite significant difference between North America and Japan. Reasons may be as follows (GFMS 2013, 2014, 2015, 2016):

- The U.S. experienced a steady recovery of the construction industry, since the crisis in 2008.

- Major infrastructure projects are started by the U.S. government to boost the public construction industry.

- The results could indicate that car use in the U.S. is more popular and therefore requires more demand. A reason for this could be the extent of the nation and the long distances that needed to be covered by transport (IEA 2015*a*).

- Japan's industry is more focussed on the manufacturing of electrical and electronic products (BBC 2013).

2.3. INFLATION CORRECTION

2.3.1. INFLATION CORRECTION

Inflation is the "increase of prices of goods or services over time". The costs of a basket of goods from the store in one year, will, when inflation occurs, be more in the next year. For this reason consumers will spend their money, instead of saving it, which is good for the economy. Because of this, governments favour inflation of a few percentages per year (Investopedia 2016*d*).

For the price of copper, it means that for one dollar, one will get less copper nowadays, than one would have got in the early sixties. Figure 2.16 shows this continually upward trend of the copper price (nominal price).
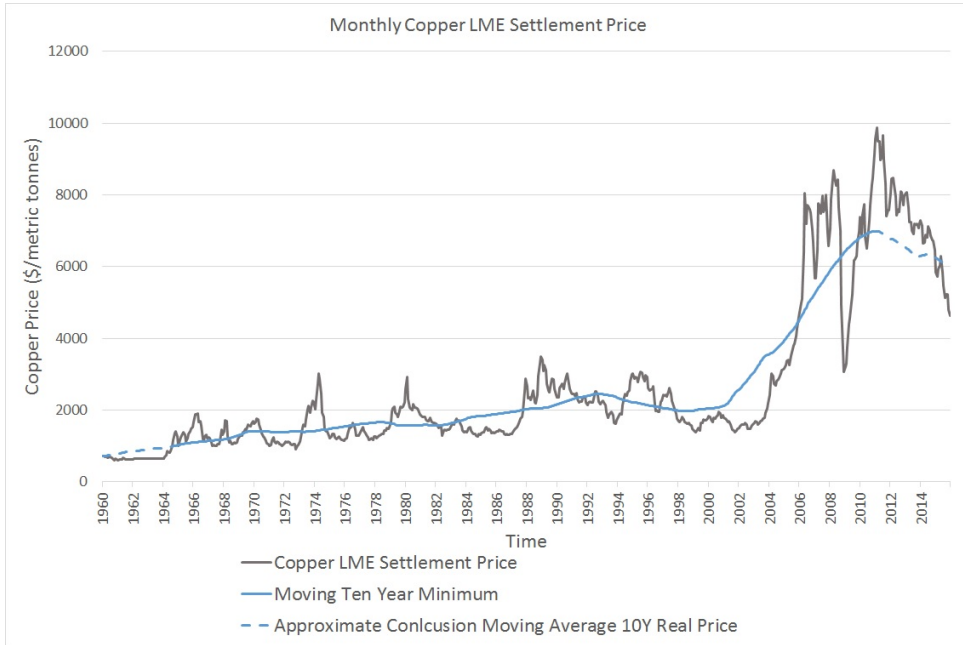
Figure 2.16: Ahead of the more detailed explanation in section 3.1, the moving average method is used to show the historical trend of the copper price, which is continually going upward.

However, in order to compare events in the sixties and seventies with the events happening nowadays, the price needs to be converted into a present day value (real price). Monthly inflation rates are reported online (US Inflation Calculator 2016). By using equation 2.1, the time series of the monthly copper LME settlement price are converted to the real price (Brealey & Allen 2011*a*).

$$P_{real_m} = P_{nominal_m} * \prod_{t=m}^{t=Dec_{2015}} \left(1 + \frac{i_t}{12}\right) \tag{2.1}$$

P_{real_m}	= Real price in month m
$P_{nominal_m}$	= Nominal price in month m
i_t	= Inflation in month t

Later in this thesis, some used time series are based on yearly averages, instead of monthly figures. The monthly inflation figures need to be compounded to yearly inflation figures, before these time series can be corrected. This is done by equation 2.2.

$$i_y = \prod_{t=jan_y}^{t=dec_y} \left(1 + \frac{i_t}{12}\right) \tag{2.2}$$

i_y	= Inflation in year y

i_t = Inflation in month t

The results of applying equation 2.1 on the monthly copper LME settlement price are shown in figure 2.17. As can be observed, the continually upward trend is replaced by an alternating upward and downward trend. Those trend breaks will further be discussed in chapter 5.
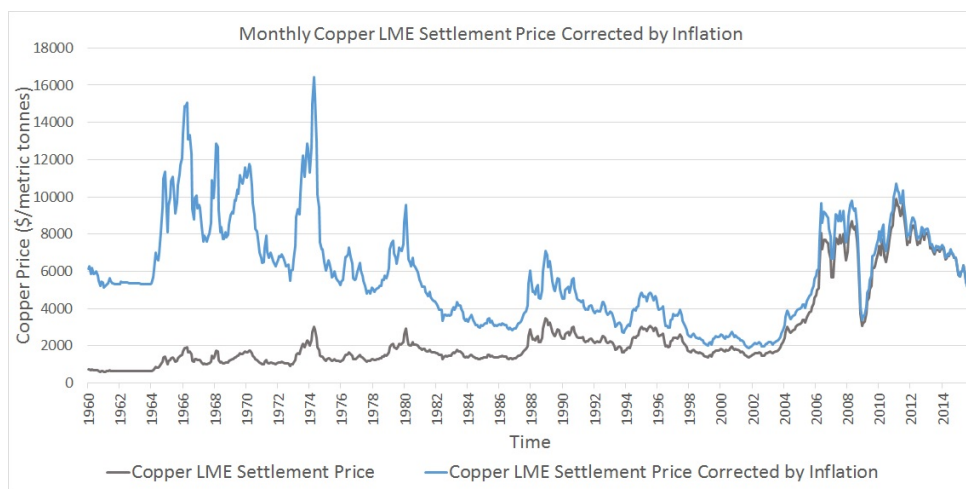
Figure 2.17: The monthly copper LME settelement price and the time series, which is corrected by the inflation.

2.3.2. Inflation Error

The example of the basket of goods, stated in the previous subsection, is an actual method of how inflation is measured. A survey of buying a basket of goods and compare the price with previous surveys. This basket of goods exist out of popular products, like shoes, pineapple or gasoline, and varies over time (The Guardian 2012). Several times a year, numerous of those surveys are done to measure these consumption expenditures. Svedberg and Tilton (2003) have recognized a few biases in this method, which cause an overestimation in the range of 0,9 and 2,0 per cent per year. These biases are (Svedberg & Tilton 2006):

- Substitution bias: a situation wherein buyers shift to products with falling prices and which is not implemented in the inflation measurement.

- New goods bias: new products are taken into the measurements long after these products were actually introduced. However, the products show a significant price drop in the first years after introduction.

- The pure-quality bias: the implementation of improved products, wherein the improvements they reflect are ignored.

INFLATION ERROR IN THE IMPACT ASSESSMENT

In anticipation of what will be explained in the methodology later and which is a crucial element in the ranking and evaluation of the importance of indicators and drivers, this error seems less relevant and will be ignored in these chapters. To explain why, the core formula used (equation 2.3) is briefly explained in advance (Roache & Rossi 2009).

$$S_{IMF} = \frac{x - x_{expected}}{\sigma} \qquad (2.3)$$

S_{IMF} = Surprise component
x = The real price
$x_{expected}$ = The price in how it was expected
σ = Standard deviation

The formula measures the difference between the real price and the expected price. This is considered the impact of an event. To be able to compare the surprise of different events in different times, it is scaled by the standard deviation. The formula is explained in more detail in section 5.2.1. By implementing the error, as suggested previously, the equation looks like:

$$\frac{(x \times \varepsilon) - (x_{expected} \times \varepsilon)}{\sigma \times \varepsilon} = \frac{(x - x_{expected}) \times \varepsilon}{\sigma \times \varepsilon} = \frac{x - x_{expected}}{\sigma} = S_{IMF} \qquad (2.4)$$

So to conclude, the error won't have an influence on the impact assessment.

INFLATION ERROR IN OTHER ASSESSMENTS

The significance of indicators is mostly shown with causalities, argued by for example correlations and trend analyses. Most of these are derived from relative differences and the multiplication of it by an error won't make a difference in the conclusions.

However, it is important to be aware of this error. Conclusions can't be simply based on absolute terms, without stating this error. For this reason this situation will be avoided.

3

MOVING METHODS

In this thesis several statistical measures are used as analytical methods. An average, standard deviation and correlation can be calculated for the whole time series. However, when looking deeper into a certain period of the series, the tools can be modified by changing the time span. This results in values, specifically true for those periods. If, subsequently, the time span is shifted and the measure is recalculated, an development or evolution of the particular measure is found, the method moves over the whole time series. In further sections, an explanation is given about this moving average, - standard deviation and - correlation. Furthermore is an other variant of the correlation used, the cross correlation. This will be discussed as well.

3.1. MOVING AVERAGE

The moving average is an excellent method to determine the relevance of an event. For instance, the average price for a day would indicate the influence of a particular news item that day. When that average is stretched to a weekly average, it appears that the specific news item is accompanied by several more items and the specific influence of that item fades away. If the impact is still notable, the news item was quite important. When the item's impact was big enough to influence the monthly average, it can be said the news item was quite relevant. It could be even considered significant, when its impact is still recognizable in a one year moving average. This way of thinking enables us to filter noise and by increasing the time span, more and more events will be filtered out. The most important events keep showing up. Equation 3.1 shows the formula for the moving average.

$$\bar{P}_T = \frac{1}{q} \times \sum_{t-\frac{q-1}{2}}^{t+\frac{q-1}{2}} P_t \tag{3.1}$$

$\bar{P}_T$ = moving average of the price for time span T in years
P_t = copper price in month t

23

q   = amount of months in time span T

Calculating moving averages for different time spans appears to be a good method to separate data with short and long term impacts. Those optimal values can be found by simulating the formula for different combinations of time spans until all predefined goals are met. For this research two optimal values are determined for time span T. These values are stated below, including the goals they achieve.

1. The one year moving average:

   - All minor events deviate from this line. This enables the possibility to eliminate all minor events, but not bigger events.
   - All, USGS mentioned events are still identifiable and are not eliminated.

2. The ten year moving average:

   - Separates all long term events/developments from the short term events by eliminating the short term events.
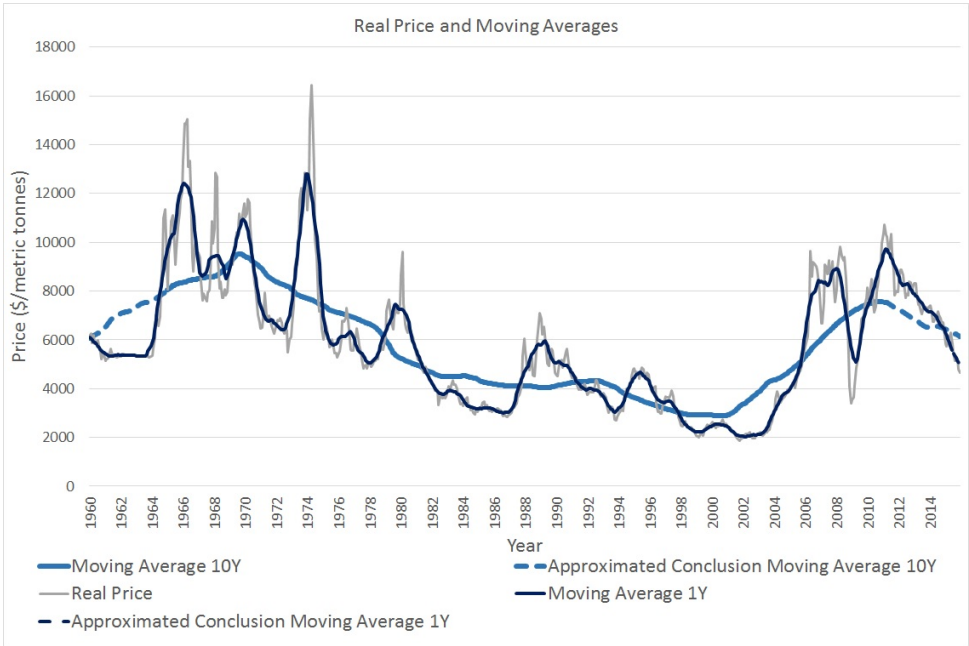
Figure 3.1: The real price, the one year moving average and the ten year moving average shown. Every time series is a deviation from the following and the longer the time span of the moving average, the more (short term) events are eliminated.

Figure 3.1 shows the two moving averages compared to the real prices. As the time span of the average increases, the smoother the series becomes. This method seems ex-

cellent in eliminating the influence of relative small events. However, the events and certain impacts need to be connected by making a causality. If the causality made is wrong, the wrong event would be cancelled out and the impact of the event, which should have been ignored, is exaggerated. The method for this is discussed in chapter 4.

Error

The time series cover the period of January 1960 - December 2015. Equation 3.1 calculates the average of a time range which covers the period $-\frac{1}{2}T$ to $\frac{1}{2}T$ for month t. This means that if t = January 1960, the range will cover a period with no data.

In this thesis an alternative is used to cover the periods in which this error occurs. Instead of (sophisticated) guessing, the assumption is made that for the period 1955-1959 and 2016-2020 no significant events did or will happen. The consequence would be no price changes. So, the closer the moving average approaches the start or end value of the time series, the more weight this value gets in the moving average. Accuracy of this method for the period 2016-2020 can't be defended, because a look into the future is not possible. This is different for the period of 1955-1959. Other price indexes, such as the U.S. Producers Price Index, published yearly averages. This index shows no change of price, with the exception of a spike in 1956 (Edelstein 1998). This means that the moving average, as calculated in this thesis, will be a slight underestimation. So why continue to use this function? The approximation of the conclusions of the moving average series can still be used to measure the impact of the events. The assumption that nothing changes will result in the moving average approaching the level of no change. All events in the time series will get a confined time span in which they affected the price. Within this time span they are not influenced by unknown events outside the time span of the whole time series. The goal, of measuring and ranking events, can be achieved by applying this alternative. The approximation is also shown in figure 3.1.

3.2. Moving Standard Deviation

Another method to analyse the time series is the standard deviation. This measurement represents the variation of a time series and therefore the volatility. A low standard deviation indicates that most data points are located close to the mean. A high value means that the points are scattered on larger distances from the mean. A high standard deviation indicates a high uncertainty (National Institute on Standards and Technology 2016). In a similar way, as in section 3.1, the calculation of the standard deviation can be moved over a time series (equation 3.2). The result is a visualization of how the uncertainty develops over time. By understanding the uncertainty, the impact of events in different periods of time can be put into perspective.

$$\sigma_T = \sqrt{\frac{\sum_{t+\frac{q-1}{2}}^{t-\frac{q-1}{2}}(P_t - \bar{P}_{T,t})^2}{q}} \tag{3.2}$$

σ_T	= moving standard deviation for time span T in years
$\bar{P}_T$	= moving average for time span T in years
P_t	= copper price in month t

q   = amount of months in time span T

Depending on the goal, an optimal time span can be determined by simulation. However, the standard deviation in how it later will be used, comes hand in hand with the moving average. In those cases, both time spans need to be equal. The 10 year moving standard deviation is shown in figure 3.2. Different periods of low and high uncertainties are now recognizable in the time series.
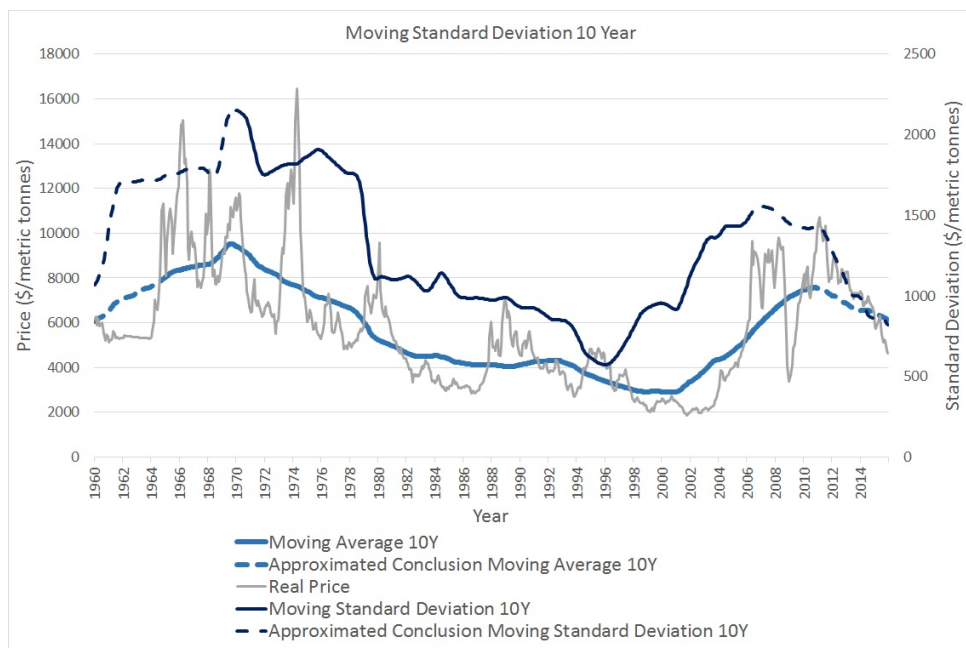
Figure 3.2: The real price, the ten year moving average and the ten year moving standard deviation. High price levels seem to be accompanied by high volatilities.

ERROR

Just as section 3.1, there is an important error present at the conclusion of the moving methods. The time range of the error for the moving standard deviation is twice as big, because of the dependency on the moving average. As soon as the affected data points of the moving average are used in the calculation, the moving standard deviation will be affected as well. The approximation is shown in figure 3.2.

3.3. MOVING CORRELATION

The last discussed technique, is the correlation. This method calculates the relationship between two time series and can therefore be used as a measure for the significance of an external factor as indicator for (future) developments in the copper market. However, this method calculates the relationship, it does not tell how to interpret the relationship.

The series can be one way or the other, but can also be dependent on a third, non described, component. The initial formula for the correlation is as follows:

$$r_l = \frac{\sum (P_t - \bar{P})(Y_t - \bar{Y})}{\sqrt{\sum (P_t - \bar{P})^2 (Y_t - \bar{Y})^2}} \tag{3.3}$$

r_l	= correlation for time shift in l lags
$\bar{P}$	= average of real copper price
P_t	= real copper price in month t
$\bar{Y}$	= average of series Y
Y_t	= value for series Y in month t

Furthermore, it is likely that this relationship varies over time and by modifying the equation into a moving form, a time series is retrieved which helps to interpret the relationship. The result is equation 3.4.

$$r_T = \frac{\sum_{t+\frac{q-1}{2}}^{t-\frac{q-1}{2}} (P_t - \bar{P}_{T,t})(Y_t - \bar{Y}_{T,t})}{\sqrt{\sum_{t+\frac{q-1}{2}}^{t-\frac{q-1}{2}} (P_t - \bar{P}_{T,t})^2 (Y_t - \bar{Y}_{T,t})^2}} \tag{3.4}$$

r_T	= moving correlation for time span T years
$\bar{P}_T$	= moving average for time span T in years
P_t	= copper price in month t
$\bar{Y}_T$	= moving average of series Y for time span T in years
Y_t	= value for series Y in month t
q	= amount of months in time span T

By simulating the moving correlation for different time spans, the most optimal time span can be determined. In this research, a time span of 10 years has been valued as optimal. An example is shown in figure 3.3 for the moving correlation between the copper and oil prices.

The time series in figure 3.3 shows two types of behaviour. One with a varying correlation in the range of -0,8 to 0,8 in the period 1960-2000. This suggests that there was no correlation between the copper and oil prices. The second type of behaviour is a high correlation between the two series after 2000. However, before causalities can be made, a critical analysis of the series has to be done. After all, high copper prices can be caused by oil prices, but also the other way around. Alternatively, price series maybe influenced by a third factor[1]. This analysis is done in more detail in section 7.2.2.1.

---

[1]Possible hypothetical scenarios are:

- Rising oil prices cause rising costs, and consequently rising copper prices.
- Low copper prices boost the cost efficiency of electric vehicles. As a consequence the demand (and price) of oil drops.
- A boom of economic prosperity for a large part of the global population requires a high demand in oil and copper. Following this, both commodity prices rise.
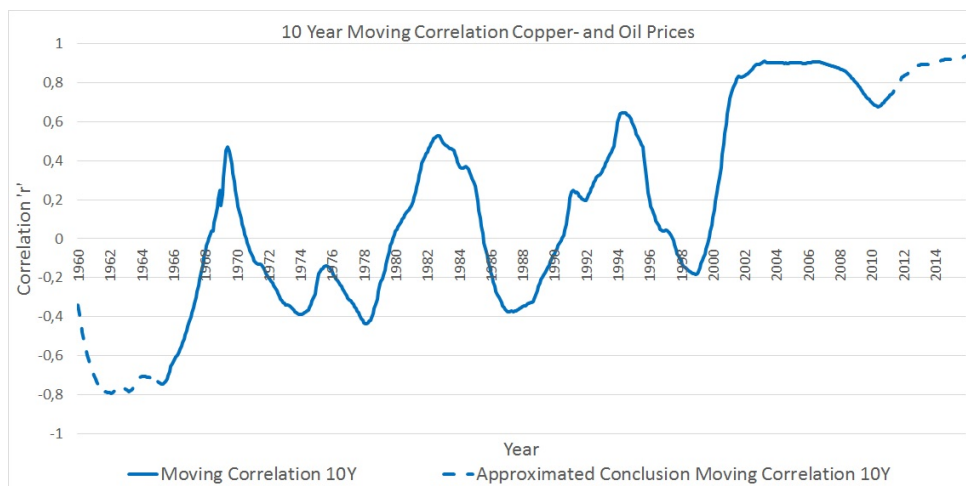
Figure 3.3: The time series of the copper - and oil prices are used to show the moving correlation between both parameters. Section 7.2.2.1 shows an detailed analysis of this correlation.

ERROR

Just as stated in section 3.1, an error of the moving correlation affects the conclusions of the time series. The approximation is shown in figure 3.3.

3.4. CROSS CORRELATION

In the occasion that two time series show the same behaviour, but one of them is delayed, a low correlation would be measured. The two time series are shifted relatively from each other and by applying this shift in the formula for the correlation, a high correlation will be found. This is very useful, because if a change in series Y precedes a change in the series X, Y would be an early warning indicator for X.

To visualize this, a basic example is shown in figure 3.5. Two sine curves are plotted, which are relatively shifted from each other by $\frac{1}{2}\pi$.
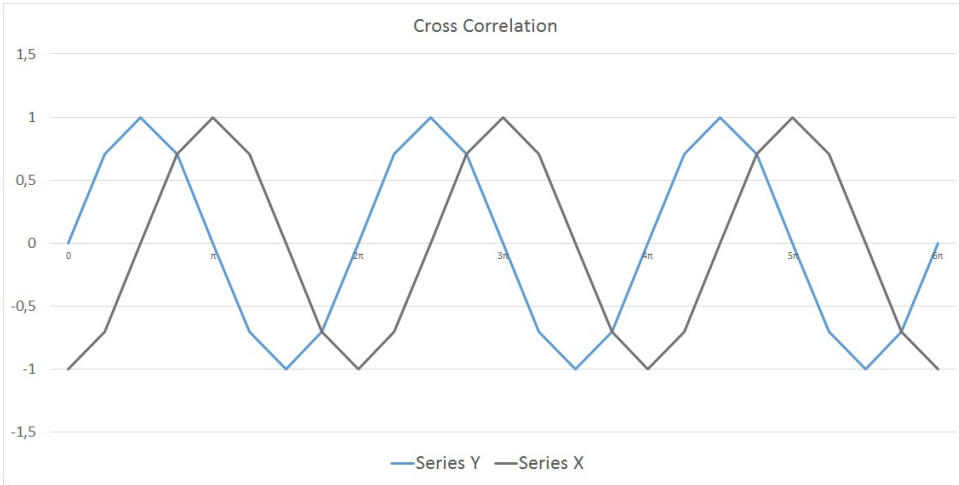
Figure 3.4: Two sinus curves are plotted, which are relatively shifted from each other by $\frac{1}{2}\pi$.

By calculating, zero correlation will be found between the two series (equation 3.3). Applying equation 3.5 and use a time shift of $+\frac{1}{2}\pi$, will result in a correlation coefficient of 1.

$$r_l = \frac{\sum (P_t - \bar{P})(Y_{t+l} - \bar{Y})}{\sqrt{\sum (P_t - \bar{P})^2 (Y_{t+l} - \bar{Y})^2}} \tag{3.5}$$

r_l	= correlation for time shift in l lags
$\bar{P}$	= average of real copper price
P_t	= real copper price in month t
$\bar{Y}$	= average of series Y
Y_t	= value for series Y in month t
l	= times shift of series Y in lags

In the example the time shift is known. But what if the shift is unknown? The equation could then be used in a simulation, wherein the correlation for several values for lag l is calculated. This results in figure 3.5 for the discussed example.
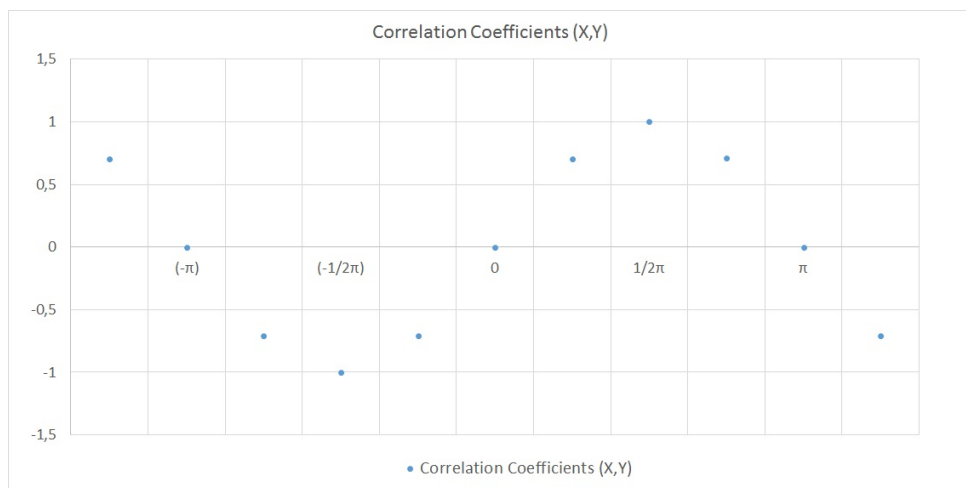
Figure 3.5: If the shift is unknown the equation could be used in a simulation, wherein the correlation for several values for lag l is calculated.

The figure shows several correlation coefficients and shows a maximum correlation of 1 for a time shift of $+\frac{1}{2}\pi$. This means that a change in the series Y precedes the same change in series X. Therefore, Y would be an early warning indicator for X.

4

ASSIGNING EVENTS

4.1. EVENTS

As stated in chapter 2 a list of "significant events, that affected the copper price" was retrieved (Edelstein 1998, 2010). The complete list is shown in the appendix, table A1. First, table A1 be categorized in several types. Later the same baselines will be used to identify the impacts and assign those to the correct events.

4.2. TYPES OF EVENTS

In section 3.1, three baselines are determined and each of them represent the influence of events. The ten-year moving average represents the influence of long term events. The more powerful the event is, the more the deviation from the expectation is. The short term events are represented by the one-year moving average and cause a deviation from the ten-year moving average. Eventually the minor events are causing the real price and are represented by the same baseline.

Combining the time series, the events and the moving averages, table A1 can be separated in three categories, or five types, of events:

1. The event is a minor event and is the cause for a spike, or a deviation from the one year moving average. The result is the real price. Shown as number 1 in 4.1.

2. The event is short term and:

   2.1. The consequence is a price movement of the one year moving average away from the ten year moving average. Shown as number 2.1 in 4.1.

   2.2. The event is dependent on an earlier event and the consequence is a price movement of the one year moving average towards the ten year moving average. Shown as number 2.2 in 4.1.

2.3. The event separates two events with both a higher opposite impact[1]. Shown
as number 2.3 in 4.1.

3. The event is long term and is the cause for a price movement of the ten year moving
average away from the consensus, which has to be defined for every long term
event separately. Shown as number 3 in 4.1.

An example of each type of event is shown in figure 4.1.
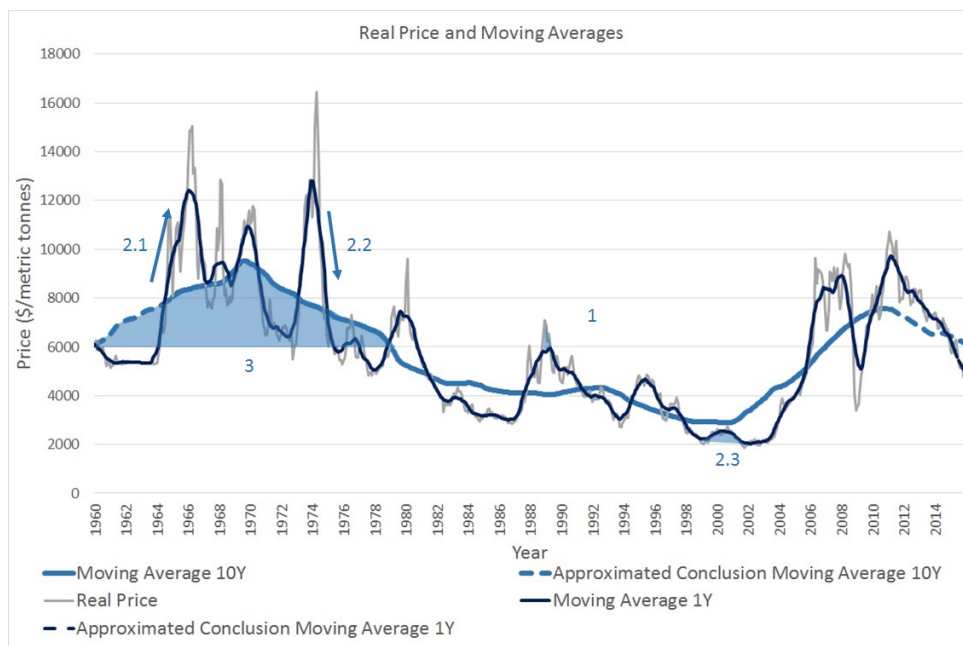
Figure 4.1: Examples of the five types of events are pointed out in this graph.

By connecting the events mentioned in table A1 to the correct years, the events of
type 2.2. can be filtered out. Those events are consequences of the real causes and are
most often strategic measures to balance the price again. An example would be the re-
lease of stockpiles. This is a countermeasure to high prices which only would occur if
the preceded event causes a rise in price. For these reasons, those events are for now
ignored. This brings the list down to 26 events, of which 3 are considered to be long term
developments, 3 events are considered to cause only extreme spikes and 20 events have
short term consequences.

---

[1]A good example of this occurred at the change of millennia. An Asian recession was followed by an uplift in
demand and another (global) recession. The uplift in demand caused a short rise in the price and therefore
it had a positive impact. However, the impact does not express in a deviation from the moving average, but
in a deviation from an alternative short term consensus, set by the two recessions. This particular example is
pointed out in figure 4.1 as number 2.3.

Table 4.1: Significant Events.

Number	Event
	Long Term Events
1	Vietnam War
2	Successful implementation of flotation technology
3	China Boom
	Short Term Events
4	Record high production rates
5	Strong demand growth
6	Longest most severe strike to date
7	Unknown Dip
8	Second stage nationalization Chilean copper mines
9	Unknown Dip
10	Third stage nationalization and Chilean Coup d'etat
11	1973-1975 Recession and aftermath
12	Record high consumption
13	Early 1980's Recession
14	Draw down of inventories
15	Growing World Consumption
16	Dissolution of the Soviet Union / Political turmoil in Africa
17	LME intervention causes sharp price drop
18	Strong global demand growth
19	Global inventory decline
20	Asian economic crises / Rapid expansion of global production capacity cause large global surplus[1]
21	Asian demand growth / Production cutbacks reduced oversupply[2]
22	Early 2000's Recession
23	2008 Global Economic Crisis
	Minor Events
24	Oil Embargo
25	1979 Oil Shock
26	Sumitomo Corp. Copper Affair

Next step is to asses the impact every event has caused.

4.3. ASSIGNING EVENTS

4.3.1. MARKING THE PEAKS AND TROUGHS

The time series can be split up into several peaks and troughs. A peak is the period be-
tween two intersections of both baselines, whereby the data in between forms a (rela-
tive) maximum. If it is a relative minimum, it is considered to be a trough. All impacts
are shown in figures 4.2 and 4.3.

---

[1] Both events occurred in the same time period and strengthened each others impact.
[2] Both events occurred in the same time period. Because of their opposite impact, the two events weakened
each others impact.
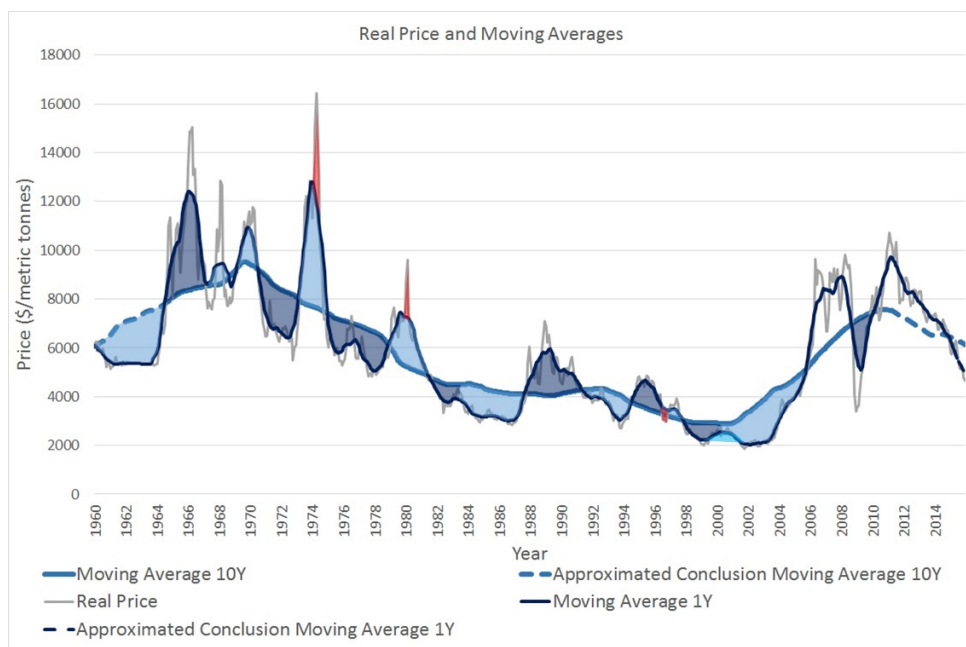
Figure 4.2: All deviations of the one year moving average from the ten year moving averages are marked in blueish colors and are considered to be the impact of short term events. The deviations of the real price from the one year moving average are coloured red and are considered minor events.
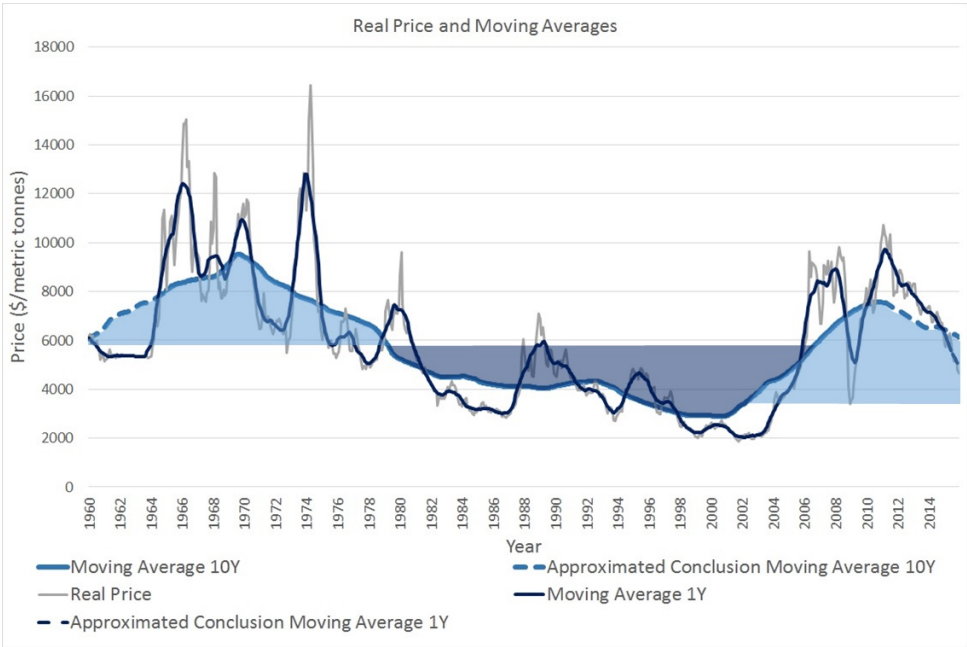
Figure 4.3: All deviations of the ten year moving average with a predefined consensus are considered to be the impact of long term event and are coloured blueish.

4.3.2. ASSIGNING EVENTS TO THE PEAKS AND TROUGHS

The events stated in table 4.1 can now be assigned to the peaks and troughs shown in figures 4.2 and 4.3. The time of the two intersections will define the time span of the impact caused by the event. This time span can be different from the time of occurring, which is provided in the appendix, table A1. This is due to the impact, which could continue to influence the market long after the actually event occurred.

Table 4.2: The impact is indicated by the moving average method. For the ten year moving average it means that an event or development, which occurs five years later, already affects the moving average. Therefore, is the time span used for the indication of the impact different from the time span that the event or development actually occurred.

Start	End	Event Causing the Impact
		Long Term Events / Developments
1960	1979[1]	U.S. Involvement in the Vietnam War[1]
1979	2006	Successful implementation of flotation technology
2006	2015	China Boom
		Short Term Events / Developments
1960	1964	Record high production rates
1964	1967	Strong demand growth
1967	1968	Longest most severe strike to date
1968	1969	Unknown Dip
1969	1970	Second stage nationalization Chilean copper mines
1970	1973	Unknown Dip
1973	1974	Third stage nationalization and Chilean Coup d'etat
1975	1978	1973-1975 Recession and aftermath
1978	1981	Record high consumption
1981	1984	Early 1980's Recession
1984	1987	Draw down of inventories
1987	1991	Growing World Consumption
1991	1992	Dissolution of the Soviet Union / Political turmoil in Africa
1993	1994	LME intervention causes sharp price drop
1994	1996	Strong global demand growth
1996	1997	Global inventory decline
1997	1999	Asian economic crises / Rapid expansion of global capacity cause large global surplus
1999	2001	Asian demand growth / Production cutbacks reduced oversupply
2001	2005	Early 2000's Recession
2008	2010	2008 Global Economic Crisis
		Minor Events
1974	1974	Oil Embargo
1979	1980	1979 Oil Shock
1996	1996	Sumitomo Corp. Copper Affair

[1] The Vietnam War actually happened between 1959 and 1975. The escalation of the war, that lead to an increase in U.S. involvement occurred in 1964 and in 1968 the U.S. involvement reached its peak(US Department of State, Offiee of the Historian 2013a). As explained in the text, the method, used to measure an events impact, has the characteristic to tone down extreme values and stretch the time span of the impact.

4.4. REMARKS

It can be seen that single events are connected to the marked peaks and troughs. Although the USGS suggests that the events had a significant impact, in reality the situation is more complex. Later on in this research, the time series will be broken down further and other indicators and drivers will be discussed. For now there is enough information to determine the size of the peaks and troughs. In other words: to measure the impacts on the market, which were caused by a set of events at the period of time.

4

5

IMPACT ASSESSMENT

5.1. INTRODUCTION

The events earlier discussed affected the copper market. Previous chapters discussed the methodology of how these events are assigned to the impact they caused. This chapter will describe how two characteristics of those impacts are analysed.

- The actual impact an event caused. This will be explained in section 5.2.

- The characteristics of the relative extremes in the peaks and troughs. This will be explained in section 5.2.

Understanding and quantifying those two characteristics will enable the possibility to compare and rank the occurred events.

The first characteristic can be quantified by the use of one base formula. This formula is based on a "popular technique" about a surprise component, described in an IMF Working Paper (Roache & Rossi 2009).

5.2. IMPACT RATING

5.2.1. LITERATURE

In 2009 the IMF published a working paper on how to measure the effects of economic news on commodity prices. Here, they introduced the surprise component S. This is the distance between the actual price P, and the expectation $P_{expected}$, scaled by standard deviation σ. The formula is shown in equation 5.1.

$$S_{IMF} = \frac{P - P_{expected}}{\sigma} \qquad (5.1)$$

5.2.2. PROPOSED METHOD

Because the real price deviates around the one year moving average, it is assumed that the one year moving average is an approximation of the consensus for the short term.

So by replacing the consensus by the moving average and the standard deviation by the moving standard deviation, a core for the formula used in this thesis is made. The consensus described is most often the correct way. However, two of the five types require an alternative determination of the consensus.

2.2. The event is dependent on an earlier event and the consequence is a price movement towards the ten year moving average. Those events are considered to be strategic and to mitigate the extreme deviations. An example is how the LME releases or accumulates inventories in times of respectively high or low copper prices (LME 2015). These events are not used in the impact assessment.

2.3. As can be seen in figure 5.1 the opposite impact of the two events on both ends can be quite dominant. The example pointed out, is the Asian recession at the end of the 90's. This was followed by an uplift in demand and a global recession. The uplift in demand caused an short rise in the price and therefore it had a positive impact. However, the specific impact does not express in a deviation from the moving average, but in a deviation from an alternative short term consensus, set by the two recession. To measure the impact of this event, the alternative consensus is determined by extrapolating both ends of the event's impact.
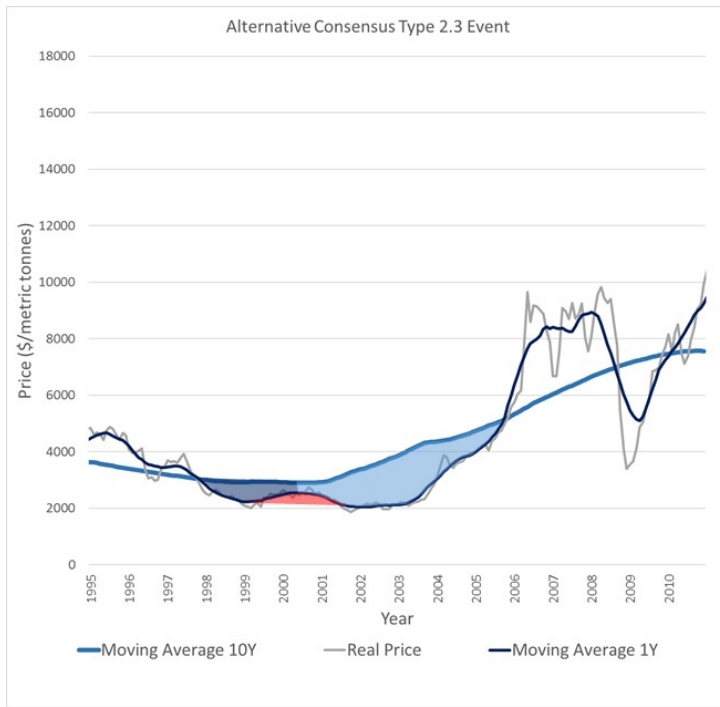
Figure 5.1: A type 2.3 events. An uplift in Asian demand (red coloured peak) that is separated by the Asian recession of the late 90's and a global recession in the early 2000's (light and dark blue coloured troughs). The impact of both recession is that high, that the impact of the short uplift, is not expressed in a deviation from the moving average, but in a deviation from a short term consensus, set by the two recession.

The formula is still not sufficient. This is due to the chaotic behaviour of the market and the influence of psychological aspects[1] (C Tapia Cortez & Sammut 2015).

Three characteristics are recognized, for which the formula needs to be tested. If the characteristics are not covered, the formula needs to be modified. Those characteristics are:

1. An event's impact is time dependent. Eliminating this dependency would enable the possibility to compare the impact of different events in different periods of time.

---

[1] Edward Lorenz published in 1962 a theory in which he suggests that numerous minuscule disturbances, like the flap of a butterfly's wing, do not increase and neither decrease the frequency of tornadoes. However, they do affect the sequence of tornadoes. This means that knowledge of all small disturbances need to be gained to make accurate predictions about the weather pattern. This is the so called "Chaos Theory" (Lorenz 1972).

In 2015, Cortez et al. states that the chaos theory is applicable to the mining markets, due to the impossibility of measuring uncertainties and the cyclical nature of these markets. Important factors which affect the supply and demand for commodities are respectively changing technology and changing human behaviour. Both huge uncertainties which can't be predicted for the long term (C Tapia Cortez & Sammut 2015).

2. The time span of an event's impact. The impact of an event needs to be measured over the whole time span.

3. The impact of an event does not increase linearly, as the price moves away from the consensus.

5.2.3. TIME DEPENDENCY

In periods of high uncertainty (high standard deviation), the impacts are generally larger in nominal values, compared to the impact of events in times of low uncertainty. Scaling enables the possibility to compare events over the whole time range. The elimination of the dependency is already implemented in the original formula by dividing the difference in real and expected price by the standard deviation.

5.2.4. TIME SPAN

Every event's impact shows a different behaviour in the form of varying time spans and varying extreme values in the peaks and troughs. The original formula, as it is proposed by the IMF, is only based on one data point. Because its purpose was to measure the impact of news items, which are relative extremely short term. The length of an event's impact can be implemented by doing the calculation for every data point within the time span. This results in equation 5.2. The next step is the delinearization.

$$S_E = \sum_{t_{end}}^{t_{start}} (\frac{P - \bar{P}_T}{\sigma}) \rightarrow Delinearization \tag{5.2}$$

S_E = impact rate for Event e.
x   = real price
$\bar{P}_T$ = moving average of the price for time span T in years
σ_T = moving standard deviation for time span T in years

5.2.5. DELINEARIZATION

Last is the elimination of the linearity in the core formula. The chaotic characteristics of the price behaviour eliminates the possibility of a single solution. However, it is not the goal of this thesis to find an optimal solution for this, and a middle way is desired. In order to be able to analyse the earlier discussed characteristics, the formula needs to meet the following goals:

- If the price deviates extremely from the consensus, the opposite force would increase more and measures, like releasing inventories, would be taken to drive the price back to consensus (LME 2015). If the price deviates slightly from the consensus, the incentive to get the price back to normal would be less. For this reason, a goal is to rank events, which are causing a deviation, more extreme than others.

- The purpose of the chosen factor, is to rank the events. If the rank factor is too high, events with a small deviation, are overshadowed and eliminated by other events. This need to be avoided.

An exponential factor is a method to meet both goals. Although the behaviour of the market is neither exponential, it eliminates linearity and values high deviations, more than small deviations. This improves the ability to rank the events. By simulation with several exponents, an optimal exponent of 2 was determined. This value secures that events with low impacts are not overshadowed or eliminated. Taking all this into account, the used formula looks like equation 5.3.

$$S_E = \sum_{t_{end}}^{t_{start}} ((\frac{P - \bar{P}_T}{\sigma})^2) \tag{5.3}$$

S_E = impact rate for Event E.
P   = real price
$\bar{P}_T$ = moving average of the price for time span T in years
σ_T = moving standard deviation for time span T in years

5.2.6. SCALE
Due to the complexity of all the events and the actual impact they had and because of the errors inherent in the discussed formula, the values are expressed in relative terms on a scale from low to extremely high. The events with very low impacts are filtered out and these classes are ignored. The impacts are more or less equally distributed over the low, medium and high classes. The extremely high class represents the big outliers.

$0 < S \leq 10$ Low
$10 < S \leq 30$ Medium
$30 < S \leq 100$ High
$100 < S \leq 200$ Very High
$200 < S$ Extremely High

5.2.7. SUMMARY
A summary of the discussed method is visualized in a flow model (Figure 5.2). Basically the following steps and actions are described.

- An event is assigned to a certain time period.

- By answering a set of three questions, the type of the event is determined.

- Based on the type of the event, the standard method to rate the impact is executed. In the alternative path, a process will be passed trough, to determine an alternative consensus.

- Afterwards the impact rate can be calculated.

- Based on all researched events, recurring categories can be identified, together with their likelihood and the corresponding impact.

- This results in a database of categories, which can be ranked on influence they have on the copper market. From this, indicators can be determined.

Should it be the case that more explanation is desired. A case, specific for the late 70's and unrelated to the final results, is discussed in appendix 11.
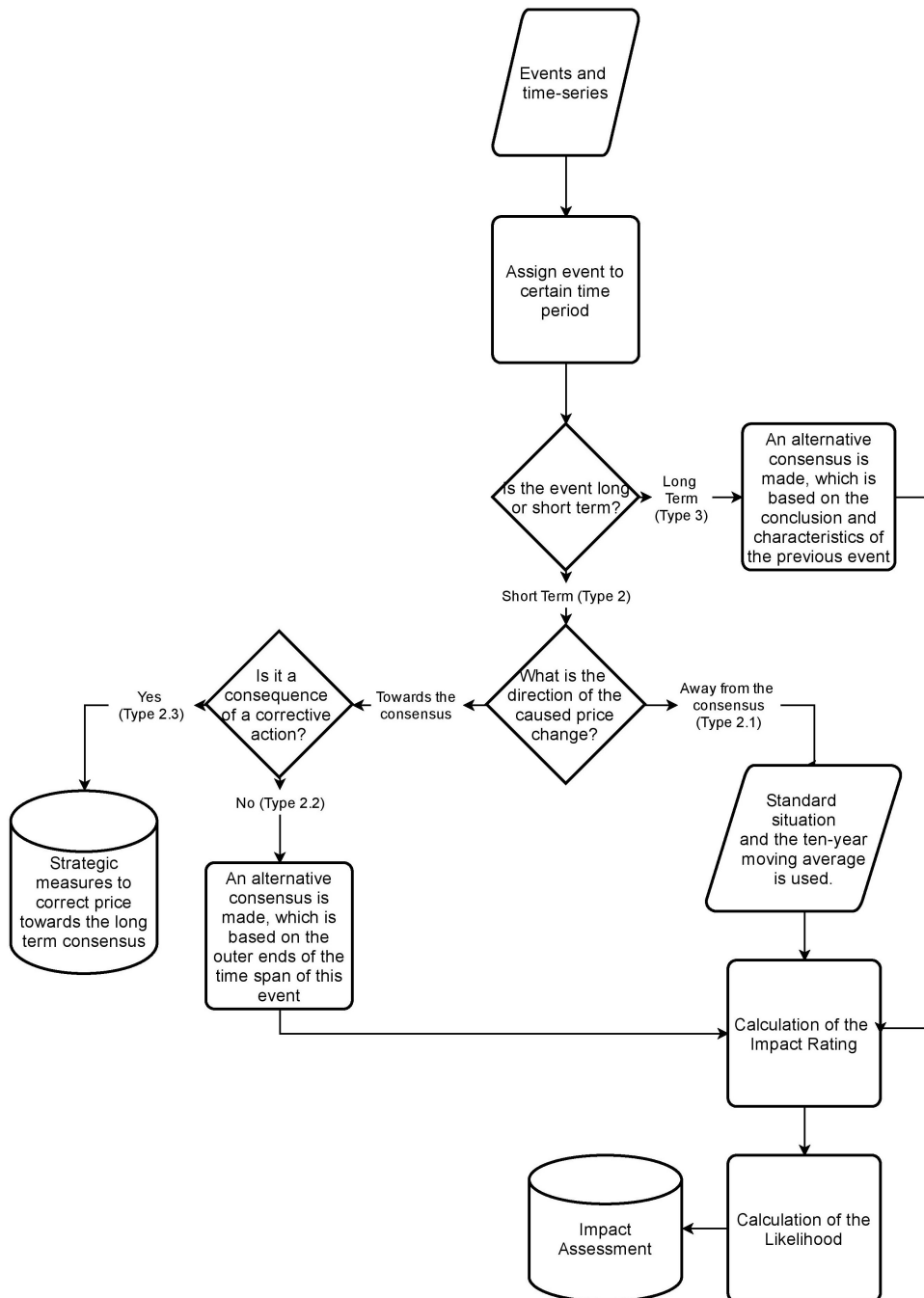
Figure 5.2: A flow diagram of the discussed method.

5.2.8. RESULTS

The case study has given a first indication of events and the differences in the order of impact they caused. Table 5.1 shows all measured impacts for the list of events selected in chapter 4.

Table 5.1: Results of the Impact Assessment.

Start	End	Event	Impact
		Long Term Events	
1960	1979	Vietnam War	Extremely High
1979	2006	Successful implementation of flotation technology	Extremely High
2006	2015	China Boom	Extremely High
		Short Term Events	
1960	1964	Record high production rates	High
1964	1967	Strong demand growth	High
1967	1968	Longest most severe strike to date	Low
1968	1969	Unknown Dip	Low
1969	1970	Second stage nationalization Chilean copper mines	Low
1970	1973	Unknown Dip	Medium
1973	1974	Third stage nationalization and Chilean Coup d'etat	High
1975	1978	1973-1975 Recession and aftermath	Medium
1978	1981	Record high consumption	High
1981	1984	Early 1980's Recession	Medium
1984	1987	Draw down of inventories	High
1987	1991	Growing World Consumption	High
1990	1992	Dissolution of the Soviet Union / Political turmoil in Africa	Low
1993	1994	LME intervention causes sharp price drop	Medium
1994	1996	Strong global demand growth	High
1996	1997	Global inventory decline	Low
1997	1999	Asian economic crises / Rapid expansion of global capacity cause large global surplus	Low
1999	2001	Asian demand growth / Production cutbacks reduced oversupply	Medium
2001	2005	Early 2000's Recession	High
2008	2010	2008 Global Economic Crisis	Low
		Minor Events	
1974	1974	Oil Embargo	Low
1979	1980	1979 Oil Shock	Medium
1996	1996	Sumitomo Corp. Copper Affair	Low

A more detailed look at the results, shows that the longer the event or development lasts, the larger the impact. When the events are categorized, as explained in section 2.1.2 and shown in table A2, the following conclusions can be derived:

- The identified long term developments have impacted the market in extreme mat-

ters. Based on these results, the following categories affected the copper market significant.

War/Conflicts

A substantial war or conflict can cause an increase in demand. Possibly, due to the use of copper in, for example, bullets, a fast replacement of equipment, maintenance and building infrastructure, high enough, to let the copper price rise and maintain it on that level for a long term.

Technology

Technological progress can decrease the costs for mining and can increase the availability of copper reserves in an order that the copper prices makes a downward trend.

Economic Boom

The entrance of a new and major economy to the global markets has driven up the demand and price in an order that replaced the conventional cycling nature of the market by a so called supercycle.

- Events, related to the global or regional increase of consumption, generally have a high impact on the market.

Those categories will be a part of the outline of chapter 7, wherein the validity of the defined causalities is checked and in which possible indicators are recognized.

5.3. CHARACTERISTICS OF THE PEAKS AND TROUGHS

In section 5.2 the actual impact of an event was rated and discussed. However, an event can impact the market slightly for a long period, or can cause an extreme deviation for a short period. The extreme deviations cause high uncertainties in the market and therefore a high volatility. In this section events are identified which cause those uncertainties.

5.3.1. BOLLINGER BANDS

Theory

The Bollinger Bands are bands on one standard deviation away form the simple moving average. The simple moving average on time t, is the average of the time span from $(t - T)$ to t. In a less volatile market, the bands contract, and in high uncertainties the bands expand. This tightening and loosening is often used as an early warning indicator on the financial markets (Investopedia 2016). Because this thesis' focus is on longer term events, this theory is not further tested or discussed.

Practice

The moving average on time t, used in this study, is not the simple moving average covering a time span from $(t - T)$ to t. This study used a moving average covering the time span from $(t - \frac{1}{2}T)$ to $(t + \frac{1}{2}T)$. The bands are shown in figure 5.3.
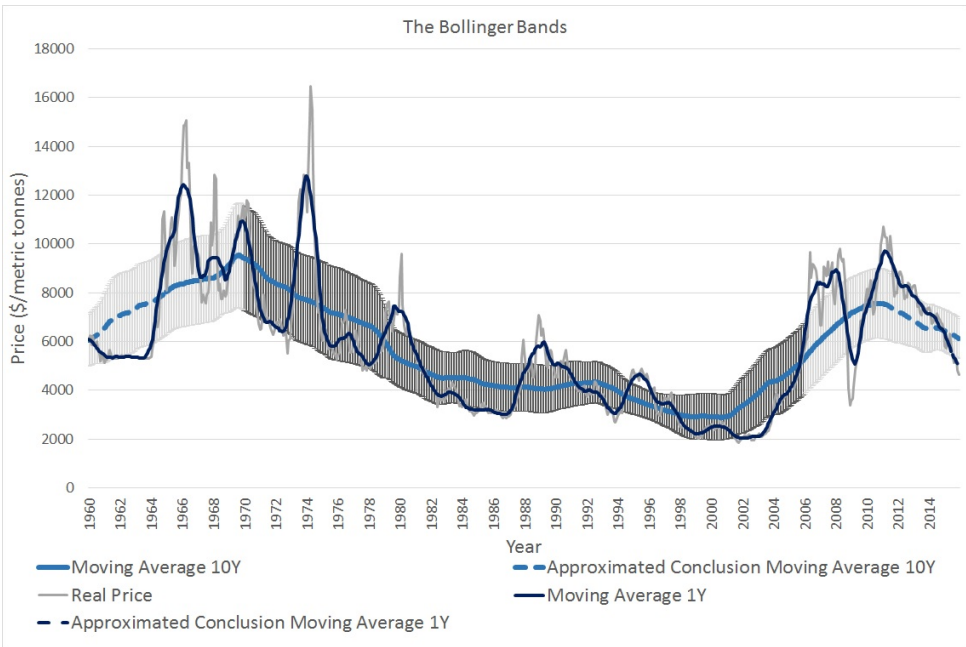
Figure 5.3: The Bollinger Bands are visualized as light and dark grey bands covering the range between the moving average and one standard deviation distance from the moving average. The outer ends are coloured light grey, due to the error in the moving standard deviations, as explained in section 3.2. The dark greyish bands are the correct representation of the moving standard deviation.

5.3.2. IDENTIFYING EVENTS

Analysing figure 5.3, moments in time can be identified, wherein the one-year moving average exceeds the Bollinger Bands. If the deviation from the consensus is more than the standard deviation, the caused deviation is considered extreme. When putting categorizing labels, as explained in section 2.1.2 and shown in table A2, it can be seen that for eight of the eleven moments, the extreme deviation is caused by an under- or over-supply of cyclic nature[1]. For 1973, the peak was caused by problems related to potential supply disruption in Chile. The other two moments; the early 2000's and 2008, are due to economic crises. The 2008 financial crisis is the only example in which the real price has fallen to extreme depth, compared to the one-year and ten-year moving average. Figure 5.4 shows these moments in time.

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[1] The cyclic nature of commodity markets is the alternation of under- and oversupply. This is caused by delays in response time of the effect of cancelled or new investments. This is best described by the cattle cycle (Rosen et al. 1993)
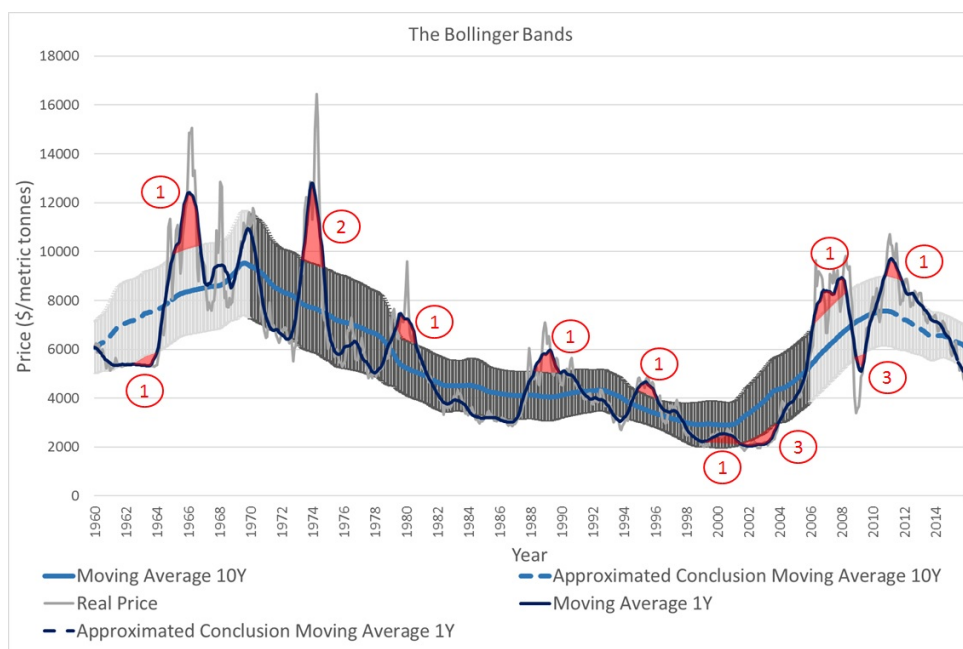
Figure 5.4: Events are identified (red), which have caused deviations, more extreme than the consensus' standard deviation. The events are numbered on category. Events related to the cyclic nature of the supply and demand are numbered with 1. The nationalization and coup in Chile, which is related to accessibility is labelled number 2. Economic crises are numbered with 3.

5.3.3. RESULTS

The main observation is that the real price and the one-year moving average, occasionally exceed the ten-year moving standard deviation in positive direction. While a deviation in the negative direction is more rare and less extreme. Based on the identified categories, which have caused those extreme deviations, the following conclusions can be derived:

Demand

Events, that cause an increase of demand and are of cyclic nature, have the tendency to drive the one-year moving average to extreme heights.

Accessibility

A conflict that increases the risks of restriction or supply disruption can cause extreme deviations. This is based on one event that occurred in the past, namely the nationalizations and coup in Chile.

Economic Crises

Several economic crises have taken place over time. Most of them did not cause a price

fall as an extreme deviation into the negative direction. However, the recession in the early 2000's and in 2008 have caused extreme deviations in negative directions from the consensus.

Those categories will be the second part of the outline of chapter 7, wherein the validity of the causalities is checked and in which possible indicators are recognized.

5.4. LIMITATIONS AND RECOMMENDATIONS

The goal of this chapter is to provide a better understanding of how events influence the copper price. In the process to reach this goal, some errors and possible improvements have been identified.

5.4.1. LINEARITY/EXPONENTIALLY

In order to eliminate the linearity in equation 5.3, an exponent is added. This is considered to be a compromise and this formula is applicable in this research. However, when more quantifiable data is needed, it should reconsider the use of this formula. More research is suggested to replace this exponent by another type of function. It is assumed that this error does not influence the results derived in this chapter.

5.4.2. ARBITRARY SCALE

The scale, made in section 5.2.6, is arbitrarily defined. The consequence is that events, with impacts on the change of levels, can be interpreted differently, when the definitions are changed slightly. However, by categorizing the events, and deriving conclusions from those groups of events, the consequences can be analysed more accurately.

5.4.3. CONCLUSIONS OF TIME SERIES

As discussed in chapter 3, moving averages and - standard deviations have errors in the conclusions of their time series. Those values, including these errors, are used in the calculation of the impact of an event in this chapter. Small changes in those values, can change the level of impact as discussed in section 5.2.6. The consequences seem negligible for the long term developments. Because their impact covers long time ranges and large price deviations, slight changes have no significant impact on the surprise component.

5.4.4. SOLITARY EVENTS

So far the assumption is continually made that a solitary event is responsible for the peak or through identified in the time series. The reality is more complex, due to interdependencies and other events that occurred at the same time. But, the impact assessment has indicated a series of categories which appear to have significant impact. Later on in this thesis, those categories will be tested for their impact and the complexity will be determined.

6

BREAKDOWN

Following the complexity of the market, a method is proposed and executed in chapter 2 to 5 to reduce a large amount of factors to only a few, but most important factors. This chapter will discuss those results and will introduce the following chapter, which will break down those categories in the search for early warning indicators. Furthermore, this chapter will discuss the encountered errors in the following chapter.

6.1. RESULTS

6.1.1. CATEGORIES

The copper market has been successfully broken down into categories. To recap, the following categories appear to be of most importance:

War/Conflicts
A substantial war or conflict can cause an increase in demand. Possibly, due to the use of copper in, for example, bullets, a fast replacement of equipment, maintenance and building infrastructure, high enough to let the copper price rise and maintain it on that level for a long term.

Technology
Technological progress can decrease the costs for mining and can increase the availability of copper reserves in an order that the copper prices follows a downward trend.

Economic Boom
The entrance of a new and major economy to the global markets has driven up the demand and price in an order that it replaced the conventional cycling nature of the market by a so called supercycle.

Demand

Events that cause an increase of demand and are of cyclic nature, have the tendency to drive the one year moving average to extreme heights.

Accessibility

A conflict that increases the risks of restriction or supply disruption can cause extreme deviations. This is based on one event that occurred in the past, namely the nationalizations and coup in Chile.

Economic Crises

Several economic crises have taken place over time. Most of them did not cause a price fall of the copper price. However, the recession in the early 2000's and in 2008, have caused extreme deviations in negative direction from the consensus.

6.1.2. Breakdown

The categories will be used as the outline in chapter 7. Each section will discuss one of those categories and break it down into several subcategories. For every subcategory the correlation and causality is determined. The discussed factor is considered relevant, when there is a form of correlation and if a viable causality can be made.

When there is a factor recognized that is considered relevant to the copper market, it still needs to be put in perspective of usefulness. The factor can be an indicator for the copper market, but can also be an indicator for a driver, which influences the copper market. In both situations it has a form of correlation and a causality, but the use of it will be much different. Indicators, which show changes before the copper market does, are so called 'early warning indicators' and can be used to foresee the likelihood of different scenarios taking place. The eventual goal of the breakdown in chapter 7 is to find these early warning indicators. The approach to do this and important recurring definitions are discussed next.

6.2. Approach

The following chapter is divided into six sections. Every section discusses one of the six categories, as discussed in 6.1.1, and starts by explaining how the categories are broken down into subcategories. Those subcategories can differ from elements within a supply chain to indicators of prosperity. Following this breakdown, necessary information for further understanding is addressed.

The goal is to prove the relevance of each of the six categories towards the copper market and to identify indicators within each category. This is done by case studies, varying in sizes. Each of them contains an introduction, objective, data, conclusion and etcetera. The case studies are recognizable by cyan boxes around the text and figures.

Finally, the end conclusions can be derived out of the case studies, and the relevance of the categories and their indicators and drivers is determined.

6.3. SOURCE OF POSSIBLE ERRORS

6.3.1. INCONSISTENT INFORMATION

A lot of information was extracted from yearly reports. One of the main problems encountered are the different ways of reporting through the years. A consequence is that yearly figures are often corrected in the years after, this is emphasized in the following case study. This error originates from the initial source and companies or research institutes, which use the data in their studies, take over these numbers. The result is that there are a wide range of versions present for only one specific figure. To emphasize this error, an example is given below.

CASE STUDY: WORLD CONSUMPTION

The USGS is a prominent geological service and releases yearly reports on commodities, such as copper. During the collection of figures on supply and demand, a lot of inconsistencies were encountered. An example of this is the report of world consumption of copper in 1980, 1981 and 1982. Figures 6.1, 6.2 and 6.3 shows the passages from the report.

> Bureau of Metal Statistics, world consumption of refined copper declined 3% to 9.53 million tons. Stocks of refined copper in the market economy countries decreased for the third consecutive year, falling by 160,000 tons to 703,000 tons. Yearend stocks were

Figure 6.1: USGS report on consumption of copper in 1980 (USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013).

> World consumption of refined copper in 1981 rose 9% to 9.44 million tons.[2] The United States was the leading world producer of mined copper, followed by Chile, the U.S.S.R., Canada, Zambia, Zaire, Peru, Poland, and 50 other countries. Copper prices

Figure 6.2: USGS report on consumption of copper in 1981. [2]Based on January to November monthly averages (USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013).

In 1982, world copper consumption con-
tinued a downward trend that began in
1979. According to the World Bureau of
Metal Statistics, refined copper consump-
tion in the market economy countries de-
clined to 6.7 million tons[2] in 1982 from the
high point of 7.3 million tons reached in
1979.[3] World refined copper inventories

Figure 6.3: USGS report on consumption of copper in 1982. [2]Based on January to November monthly averages (USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013).

While in 1981 the copper consumption rose, the report in 1982 suggests a declining trend since 1979. While there was a consumption of 9,53 million tonnes of copper in 1980, the consumption in 1981 rose to a level below the one in 1980. Finally, the 1982 report uses figures that are 20% lower, as those used in the previous years. So some of the statements made in each passage are not in line with previous statements or even negate them.

Reasons for those inconsistencies can be corrections, due to non-transparent nations or companies, which report their figures irregularly or not all. Until good information becomes available, estimations need to be done. Furthermore, large differences can be explained by the exclusion of a whole consumers group. It is possible that the figures, reported in 1982, include all nations outside the United States and that their figures are published in a different section. However, this is not clearly stated in texts.

Those errors are minimized by using the most recent versions of figures. Yearly reports often published the data of some previous years and if revisions occur, those are implemented in the thesis. In the rare occasion that a year is missing, data is extrapolated or is approximated on basis of description, this is more clearly explained in section 6.3.3.

6.3.2. ERROR ON COMPOUNDED INFORMATION

Due to the focus on events that impacted the copper market on a scale of several months to several years, it is necessary that all time series are detailed enough to identify these events. Unfortunately, a lot of information is only reported on yearly basis. Although long term correlations and long term trends can be identifiable, conclusions are confined to a more global scale.

In order to identify an early warning indicator, it would be beneficial to recognize a trend break in its time series, preceding a trend break in the copper price. If a time delay on a scale of only months is present, this delay won't show up and the early warning indicator remains unfound.

This error can be solved, by using an additional time series, which may cover a shorter length of time, but has an increased level of detail. An alternative solution would be to reason a causal relation, although this remains to be ungrounded.

6.3.3. ABSENT INFORMATION

Much of the information used in chapter 7 originates from non-transparent sources. Due to the costs or due to strategic issues, companies or research institutes often don't publish information for free. The content of this information stretches from operational information on mines (e.g. marginal costs) to the use of copper in products with patents (e.g. military equipment). This results in the use of several sources for one time series, in which the error on inconsistent information increases, to fill up gaps by extrapolating or approximating. A good example is the construction of the time series of marginal costs. Which is explained in the following case study.

CASE STUDY: MARGINAL COSTS

Marginal Costs in a Time Series

An example of how the issue of absent information is solved, is the time series for the marginal costs in copper production. Three sources were used to make this time series, and still information is absent. Extrapolating and approximating the gaps resulted in figure 6.4.
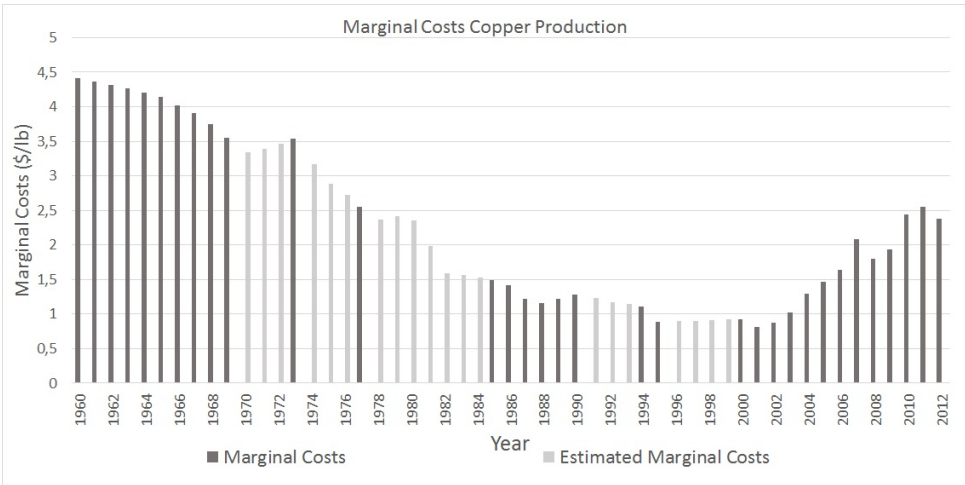
Figure 6.4: Three sources are used to construct this time series. The World Copper Industry for the period of 1960-1977, USGS for 1978-1995 and the conclusion is reported by Wood Mackenzie. But still, a lot of information is missing (Mikesell 1979, Wood Mackenzie, Bloomberg and AllianceBernstein 2015, USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013). The short peak in 1979-1980, is not based on quantitative data, but on descriptive information (Thompson 1993).

The issue of using several sources is that it could be based on different figures or it uses different criteria to determine the eventual values. The error discussed in section 6.3.1 is strengthened due to this.

The short peak in 1979-1980 is a good example in how the issue of missing information can be solved. The Base Metals Handbook, written by Martin Thompson, states: "The high prices of 1979-1980 briefly set costs rising again.", indicating that the high copper prices evaporated the incentive to reduce marginal costs (Thompson 1993).

Marginal Costs in a Cost Curve
To continue on the marginal costs, the same problem is encountered in the case study
about cost curves. Not all operational mines report their costs and the amount of mines
limits the ability to create a solid dataset. However, would someone be able to make cost
curves, then the theory behind the cost curves could certainly help in identifying and
foreseeing developments in the copper market. Because of this, two artificial cost curves
were made and the following argumentation was based on those two examples.

6

7

INDICATORS

7.1. SUPPLY AND DEMAND

Starting at the basics the market price is a result of a continuous search for a balance between supply and demand. When the demand for copper increases rapidly, a supply deficit occurs, prices rise and companies gain an incentive to ramp up production. However, expanding or starting new mines could take years to decades, resulting in a delayed response from the supply side. By the time production increases, the circumstances could have changed. Reduced demand and/or too much production cause a price fall and due to contractual or financial obligations, companies can't react immediately. Again, a delayed response occurs. This chain of events is of cyclic nature, wherein under- and oversupply alternate each other. It is considered a characteristic, applicable to commodity markets(Rosen et al. 1993). Figure 7.1 shows how these cycles occurred in the copper market over the last half of a century. According to the USGS, the peaks in each period, represent a period of high consumptions and the troughs, represent a period of either high production rates, low demand (e.g. due to a recession) or both (Edelstein 1998, 2010).
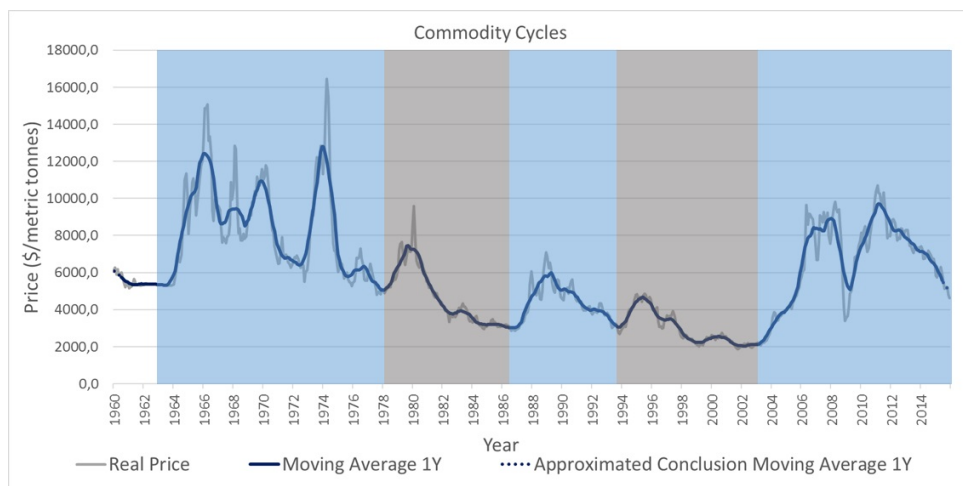
Figure 7.1: The commodity cycles in the copper market. According to the USGS, the peaks in each period, represent periods of high consumption and the troughs represent periods of either high production rates, a low demand (e.g. due to a recession) or both (Edelstein 1998, 2010).

Only five cycles have occurred since 1960. All five share only a few characteristics like a rapid price rise at the start and a less steep decline after. The length of a cycle varied between 7 and 15 years. Further, there are not many similarities.

This section will discuss the drivers on both the supply and demand side and will discuss some characteristics of these cycles.

7.1.1. SUPPLY DRIVERS

A three pillar chain is identified which relates to the supply side of the commodity cycle: company strategies, exploration and investments, mining and processing.

Company Strategies → Exploration and Investments → Mining and Processing
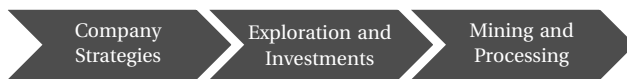
The following case studies will discuss the influence of developments in one of those three pillars on commodity cycles.

CASE STUDY: COMPANY STRATEGIES

Introduction

As the first statement suggests, it appears that every cycle starts with a rapid price rise. This is caused by an increase in the demand for copper and in its turn by economic growth. The rapid rise, indicates a surprise effect and it may be that companies where unprepared for these sudden changes.

Objective

Goal of this case study is to bring historical milestones of the main copper producing companies in context with the market and to show how their current strategies anticipate on the future market.

Current Development

As shown in 2.1, the top 10 copper producers vary in types and origin. The companies have either a diverse portfolio of commodities, or they mine mainly copper. This difference matters in determining which strategy a company needs to follow. In times of low commodity prices, a company with the focus on only one commodity, will be faced with the challenge to survive the period, without an opportunity to cut non-core activities. However, a company with a diversified portfolio, could push off non-core activities, or could cut on commodities with a less bright future. By focussing on the strategies of this latter group, commodities can be identified which are deemed to have a high potential (Finance Yahoo 2016). For this reason, some diversified companies in the top 10 are selected for an analysis of their strategies. Because the top 3 producers, Codelco, Freeport McMoRan and Glencore have their core business in copper, they are not discussed.

- **BHP Billiton:** BHP Billiton is the fourth largest copper producer. Yet, their most important contribution to the copper market was taking a share in the Escondida mine in Chile. In 1984 they made the decision that would transform the company into a "worldwide minerals company". Nowadays, BHP Billiton has five copper mines, of which the Escondida mine still represents the largest share of the company's copper production (BHP Billiton 2016, 2015). The Escondida mine is, at the moment, by far the largest mine in the world with a production of over 1Mt (ICSG 2014).

  BHP Billiton's current strategy is to increase their activities in copper. During 2016 they announced an increase of spending in exploration in copper and oil by 900

million dollar. Although only 25% of the budget flows into the copper industry, it clearly states that BHP Billiton considers copper as a "key resource that will bolster its future growth" (Reuters 2016, Mining.com 2016).

- **Rio Tinto:** No significant move into copper was made by Rio Tinto during the period 1954-1989. This changed when Rio Tinto acquired Kennecott Utah Copper. Today this is still the bedrock of Rio Tinto's copper product group (Rio Tinto 2016*b*).

  Rio Tinto believes that the demand for copper will increase rapidly in the future. They state that over the next ten years the demand will rise every 15 months by an amount, equal to current production in the Escondida mine (Rio Tinto 2016*e*). Furthermore, Rio Tinto sees technological challenges, such as decreasing ore grades or deepening mines, as opportunities for which their strategy needs be adjusted (Rio Tinto 2016*e*).

  The technological challenges and the current period of oversupply will end in a few years and Rio Tinto believes that the copper market will become a very profitable market.

- **KGHM Polska Miedz:** Another large copper producer is KGHM Polska Miedz. Less diversified than the other examples, KGHM has a long history of copper mining. Just like BHP Billiton and Rio Tinto, KGHM sees a very promising copper market ahead. For this reason KGHM is developing their largest exploration campaign in history. The goal is to become the seventh largest copper producer on the globe, with over 1Mt of production. Currently KGHM is producing 'only' 560kt (KGHM 2015, Investing News 2016).

- **Anglo American:** Anglo American has been historically involved in copper, specifically African copper. For example, initially they were large shareholders of the mines in the Copperbelt. However, due to nationalizations in the seventies, Anglo American lost their share to the governments (Konkola Copper Mines plc 2016). Afterwards it took until the eighties, before Anglo American became involved in Chilean copper. In 1995 Anglo American opened up a Chilean mine and in 2002 they acquired two mines in Chile, namely the Los Bronces and El Soldado mines (Anglo American 2016*b*).

  The fall in commodity prices, following the Chinese economic boom, resulted in a tough period for Anglo American. They decided to cut 85,000 jobs and intensify their focus on precious metals, platinum group metals and copper (Anglo American 2016*c*, Mining.com 2015*a*).

Conclusion

The discussed company strategies are focussed on the long term. Based on their predictions, a period of deficits will be followed by oversupply. Considering how activities of the larger mining companies have already shifted, or going to shift to copper over the next couple of years, a threat for a large deficit in the future has weakened.

Related to the short term, companies have no clear strategy. It takes too much time to start up a mine and projects, which are already in the pipeline, will set these circumstances. Companies appear to have less influence on this.

7

Introduction

Besides company strategies current investments and exploration give an insight into how the industry is actually prepared for an ongoing rise in global demand. In contrast to company strategies, it is hard to bring investing and exploration in historical context. This is due to the limited data available on investments and exploration. And if available, the figures are biased due to how technologies and operations have developed over time (this will be discussed in more detail in section 7.4). However, knowing about current investments and exploration and comparing them on small time leaps, would give a good insight in determining the likelihood of certain future market scenario's.

Objective

How can data on ongoing investments and exploration be used as indicators for future market developments?

Data

Investments: For the period of 2015-2024 an amount of over 77 billion dollars will be spent in investments in the Chilean copper sector. The estimated value in 2013, for the period 2013-2021 was still 86 billion dollars. These investments will be done by Codelco, private miners and medium scale miners (Chilean Copper Commission 2013, 2015). In both years the future production capacity was predicted. This is visualized in figure 7.2. Those figures include operating mines, projects that are either already in progress or still in it's (pre-)feasibility phase.
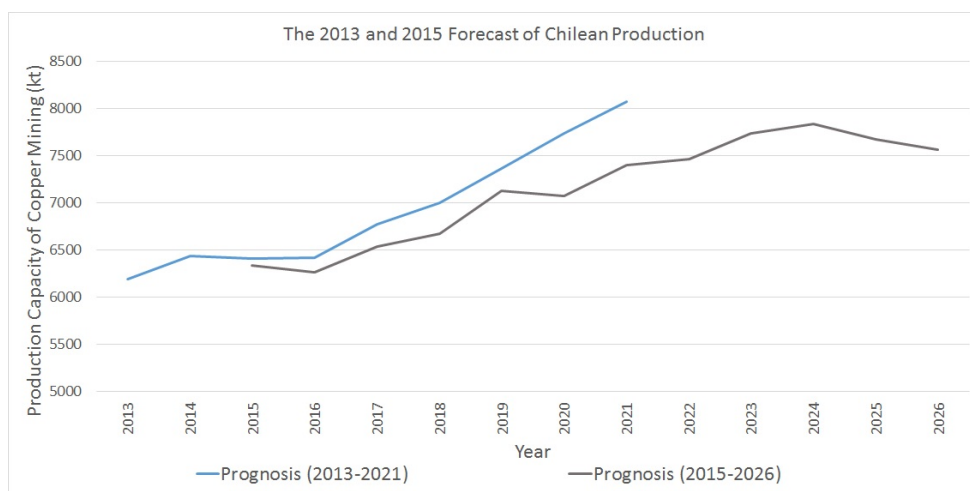
Figure 7.2: In 2013 and 2015 a forecast was made for the future production capacity in Chile. The forecast of 2015 was significantly more conservative as the 2013 forecast (Chilean Copper Commission 2013, 2015).

The forecast made in 2015 was significantly more conservative than the 2013 forecast. The currently low copper prices could be a reason for the downgrade. The Chilean production represents 30% of global production and the investments are undertaken by a wide range of companies, active in mining. Therefore, this could be considered a good representation of a global development.

Exploration: As already mentioned, BHP Billiton has increased spending on copper exploration by almost 200 million dollars (Mining.com 2016, Reuters 2016). Furthermore, Rio Tinto is slowly building up its exploration budgets on copper again and continues its strategic commitment to the copper industry (Rio Tinto 2016*d*, News.com.au 2016) and KGHM Polska Miedz is starting their largest exploration campaign in history (KGHM 2015). Only Anglo American has reduced its exploration budget overall, but on the contrary they report that their exploration budgets are now more focussed on diamonds, PGM's and copper (Anglo American 2016*a*).

Conclusion

The budgets for investments and exploration have been scaled down significantly. Most likely due to decreasing demand and consequently cut backs within the company structures. However, focussing on the major copper producers, who believe in a bright future for copper, a turning point is recognizable. Exploration budgets for copper are rising again, or the copper exploration gains more focus.

7

CASE STUDY: SUPPLY DISRUPTIONS

Introduction

A big factor in the supply chain is the influence of developments within mines. This case will focus on the significance of supply disruptions and their consequences on the market.

A breakdown is made of three types of supply disruptions. First are negative economic circumstances, such as a low copper price, which mainly affect small mines. This is due to their relatively high operating cost, causing low returns (Rio Tinto 2016*a*).

Secondly, positive economic circumstances. A high copper price can move employees to demand a higher share of the returns. This development could end up in strikes. Because the economic circumstances, both positive and negative, affect many mines, those disruptions often come in waves.

Last are the disruptions caused by special events, such as a landslide. This case study will discuss the consequences if a major mine is affected by one.

Objective

What is the influence of supply disruptions on the copper market?

Supply Disruptions caused by Negative Economic Circumstances

This paragraph will focus on the developments in the sector during the downfall of the price in the end of 2015. Smelters, as they are in the same order of magnitude as mines, are taken along in this case study.

Cochilco, the Chilean Committee Copper published in 2016 a presentation of current developments in the mining sector. Mines were sold, investments were delayed and many mines cut production. This is shown in figure 7.3.

7
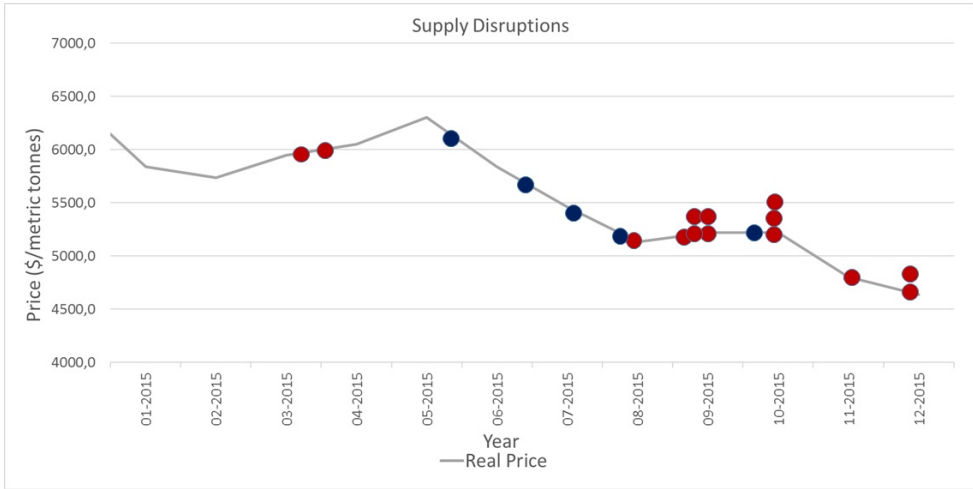
Figure 7.3: Planned cuts on global production. In red, all production cuts and closures. Project delays or re-structures are coloured blue (Chilean Copper Commission 2016).

Fourteen mines were cut in production or closed and five projects were delayed or re-structured. The relevant production values vary from about 30 kt to 150 kt and none of the mines are in the top 20 mines, which have a production above 200 kt (figure 2.9 and Chilean Copper Commission (2016)). Although a large number of mines cut production, it did not affect the trend of a declining price. However, it concerns mainly small mines and the effect of a supply disruption at a major mine remains undiscussed.

Supply Disruptions caused by Positve Economic Circumstances
In July 2011, Escondida, the largest copper mine in the world (figure 2.9) was hit by a two week strike, which caused a drop of more than half of the production. Although it caused a drop in Escondida's output, it did not in the output of the producing company Codelco. As shown in figure 7.4, the production of Codelco remained at the same level. A reason for this could be a sufficient amount of the company's stockpiles, which could overcome those kind of events (Financial Times 2011, Cochilco 2015).
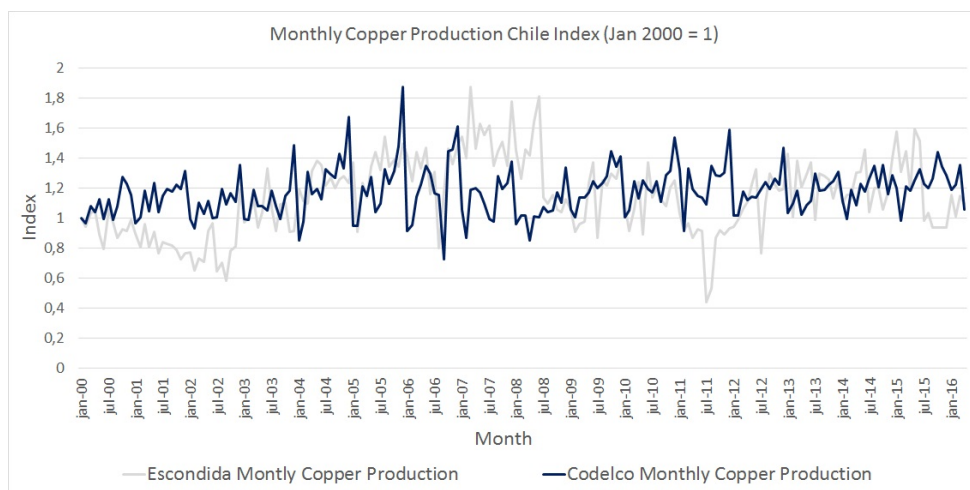
Figure 7.4: The monthly production figures are shown of the Escondida mine and of the operating company: Codelco. The figures are indexed on January 2000 = 1. The Escondida mine, taking a share of over 50% of Codelco's production, varies over time, while Codelco has a much more stable output (Financial Times 2011, Cochilco 2015).

Figure 7.5: The copper price shown for the year in which the largest copper mine in the world, Escondida, faced strikes. The price continued a trend downwards, while a major supply disruption occurred (YCharts.com 2016).

Figure 7.5 shows how the strike affected the copper market. Only a small disturbance, in the form of small peak, is visible. However, Financial Times (2011) recognized a tendency for many strikes in the year 2011, e.g. at the Collahuasi mine in Chile and the Grasberg mine in Indonesia. The consequence was that the primary supply of 2011 equalled 2010, while the consumption continued to grow.

The information of events that affected the copper market significantly, gathered from the USGS, was published in 2010, and more recent events are not discussed so far (Edelstein 2010). The wave of strikes in 2011, affecting major mines, could be a big reason for the extremely high prices of 2011.

Supply Disruptions caused by Special Events

A landslide occurred at the Bingham Canyon Mine in April 2013 and was recorded as the largest man-made landslide in history (Rio Tinto 2016*c*). But the landslide was foreseen and the operation anticipated on the slide. Operations continued after 48 hours, first ore from the pit bottom was delivered to the concentrator after 17 days and less than 10% of the equipment was damaged (Kennecott 2014, Rio Tinto 2016*c*). As shown in figure 7.6, the disruption did not have a big impact on the copper market, considering a declining price.
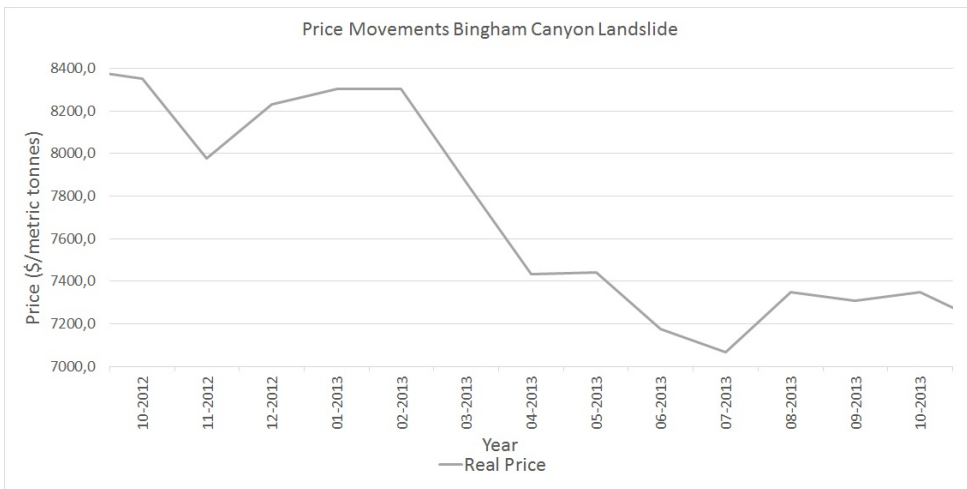
Figure 7.6: A landslide at the Bingham Canyon Mine in April 2013 was recorded as the largest man-made landslide in history (Rio Tinto 2016*c*). The disruption did not have an big impact on the copper market, considering a declining price (YCharts.com 2016).

Conclusion

Three types of supply disruptions are identified. The first are negative economic circumstances, such as a low copper price. Mines, mostly small mines with relatively high operating costs, are affected most. A wave of production cuts and closure follows, but does not seems to stop a negative trend in the market.

Secondly, is a high copper price. What follows, is that employees want to get a higher share of the company's returns, which could end up in strikes. The consequence of a strike at one mine, seems negligible, but if the development occurs at more (major) mines, it does affect the market. This kind of supply disruptions could be considered as

a major reason for the price peak of 2011.

Last are special events, such as landslides. Companies can anticipate on those events and can limit the consequences by using their own stockpiles. In many ways, the consequences are similar of supply disruptions, related to strikes. However, these events have the characteristic to occur more randomly in time and to less dependent on market developments.

CONCLUSION SUPPLY DRIVERS

Three pillars are recognized as indicators for (future) supply. First, the company strategies, which indicate where the industry is heading in the long term and how it is anticipating on a growing market and an upcoming supply deficit. This is reflected by their activities in exploration. However, cuts in investments are also identified. This could threaten the ability to close the foreseen supply deficit on the short term.

Last are the developments within the mining and processing, such as supply disruptions. This appears to be often negligible. However, if several major mines are affected by disruption in the same period, they could affect the market significantly. The kind of disruptions are mostly strikes.

7

7.1.2. DEMAND DRIVERS

The demand for traditional products, which require copper, is very much economy related. But besides those conventional ways of using copper, as explained in section 2.2.2, new ways can be identified. Copper is an essential element in achieving goals set in energy efficiency, use of sustainable energy and the reduction of carbon dioxide emissions, due to its electrical and thermal conductivity (Siemens 2014, Copper Alliance 2016*b*). The identification and validation of those new consumption patterns is very important to understand how these commodity cycles behave in the future and with what strength.

CASE STUDY: SUSTAINABLE SOCIETY

Introduction
In the progress towards a sustainable society, targets are set by governments all over the globe to reduce energy loss and -consumption and to minimize the output of carbon dioxide emissions (IEA 2015*b*). Due to its very high electrical and thermal conductivity is copper perfect to transport electricity without a big loss. Furthermore copper can be used in small appliances, without heating them (Copper Development Association Inc. 1999*a*).

Objective
This case study will discuss the biggest opportunities in the transition towards a sustainable society and the role of copper in it.

Data
Within the transition towards a sustainable society, 'energy efficiency' is an important theme. Consequently carbon dioxide emissions are also reduced. The goal of this is to reduce energy loss and -consumption. The OECD members are already improving their energy efficiency. This is visualized in figure 7.7. What is clearly visible, is that the historic trend of increasing energy use, as the GDP per capita increases, is broken. The OECD members have managed to reduce their energy consumption, though their GDP per capita has increased (The World Bank 2004, 2012*b*,,).
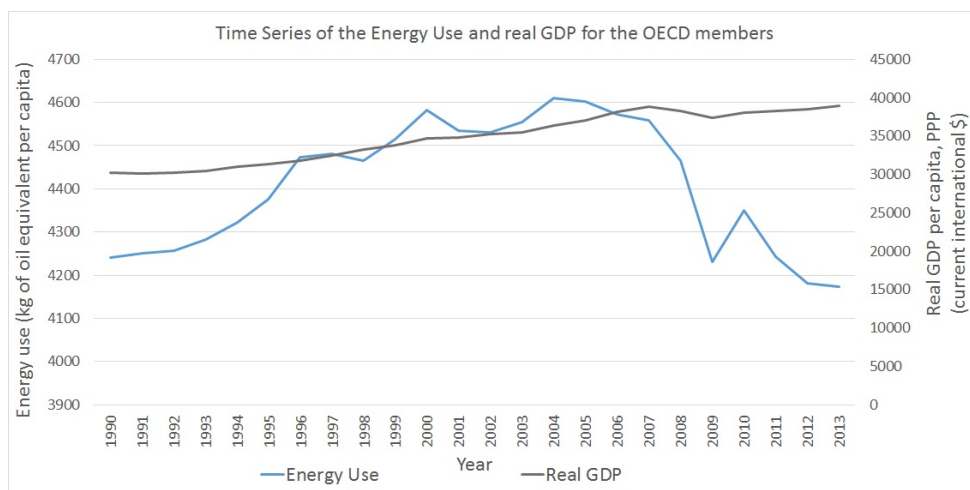
Figure 7.7: What is clearly visible is that the historic trend of an increasing energy use, as the GDP per capita increases, is broken. The OECD members have managed to reduce their energy consumption, though their GDP per capita has increased (The World Bank 2004, 2012*b*,,).

Not just the developed world, nations, such as China and India, which are in developing stages, are also putting in efforts to increase their energy efficiency (IEA 2015*b*). Although the figures rise in absolute terms, both nations are succeeding to decrease the energy use per GDP per capita. This is shown in figure 7.8 (The World Bank 2004, 2012*b*,,).
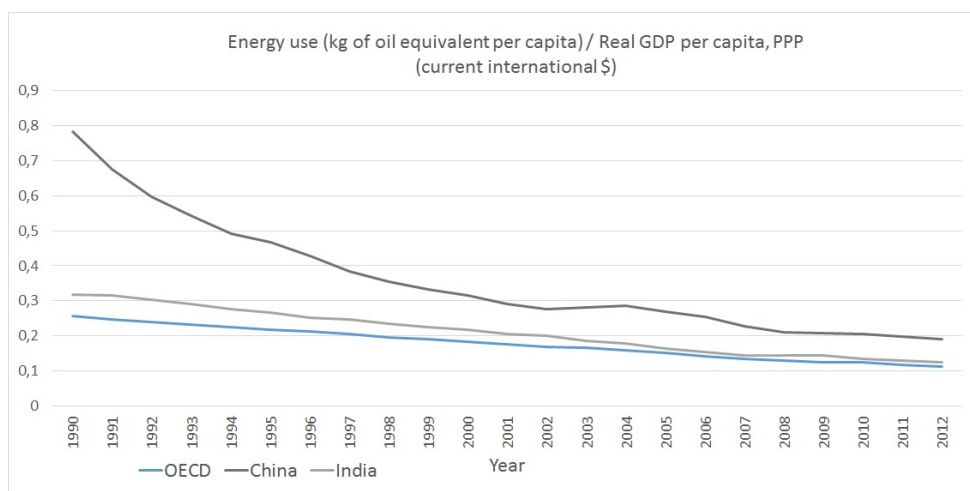
Figure 7.8: Not only the OECD members, but also China and India are succeeding to increase their energy efficiency. Although the absolute figures are rising, relative to their GDP per capita, they are decreasing (The World Bank 2004, 2012*b*,,).

Nations are succeeding to use their energy more efficiently. In addition to their efforts on establishing an energy efficient society, policies are made on reducing carbon dioxide emissions. Goals are set in using green energy, e.g. wind and solar power (European Commission 2016). This transition is very demanding on materials with outstanding electrical and thermal conductivity. As will be discussed in more detail in section 7.4.1.3, copper is a very suitable metal. Copper does not only meet these qualifications, it is very suitable for complex alloys. This latter is essential in for example solar panels (Copper Development Association Inc. 1999*a*).

Conclusion

The foundation for the key role of copper in a sustainable society is created in the drive for more energy efficiency. This requires a higher need for metals with either a high electrical- or a high thermal conductivity. The use of copper would reduce the energy loss in transport, or will cool down appliances more easy as other metals do, which will be discussed in more detail in section 7.4.1.3. The demand for these qualifications is strengthened in the use of green energy. Furthermore is copper an suitable metal for complex alloys used in the new technology.

The transition towards a sustainable society is very important for the copper market. However, aluminium is an important metal, which could compete against copper. If a solution is developed to upgrade the characteristics of aluminium, or if the price for copper becomes simply too high, it could increase the likelihood for substitution. However, the opposite has taken place and the copper price has fallen, which would reduce that likelihood.

7

CASE STUDY: ELECTRIC VEHICLES

Introduction

The desire for a sustainable society is a broad concept which can be completed in many ways. The consequences for the copper market are therefore hard to define. However, one way is to increase the use of electric cars. This development is interesting, due to the possibility to eliminate the use of fossil fuels, and it is interesting as a case, because 10-15% of the end-use of copper is related to transportation (GFMS 2013, 2014, 2015, 2016).

Objective

What is the potential impact of the transition from the use of conventional vehicles towards electric vehicles?

Data

Figure 7.9 shows the worldwide car production over the last one and a half decade (Statista 2016). With the exception of 2008-2009, production continued increasing every year. In 2015 over 90 million vehicles were produced.
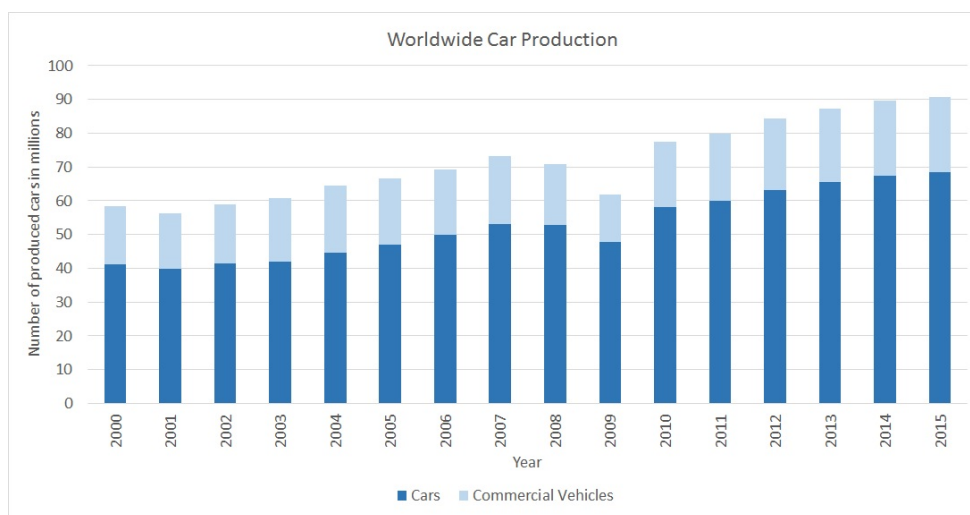
Figure 7.9: Worldwide Car Production (Statista 2016).

The amount of copper used in cars, is reported in a wide range by several sources. An often recurring average number is 25 kg per car (Copper Development Association Inc. 1998). The metal is used in the motors, wiring, radiators, connectors, brakes and bearings (Copper Development Association Inc. 1998).

With reported figures ranging from 50-80 kg per car, the copper used in electric cars is much higher (Copper Development Association Inc. 2010). Not even mentioning the average use in electric buses, trolleys or metros, which is more at 1000 kg per vehicle

(Copper Matters 2016). Prognoses about the advance of electric vehicles differ widely. For example, OPEC believes the electric vehicle will slowly grow from a share in car use of 0,1% today to not more than 1% in 2040. Bloomberg however, says that the 2020's will be marked as the lift off of the electric vehicle (National Interest 2016). Furthermore, they state that in 2015 an estimated 462.000 electric vehicles were sold and this number will rise to 41 million in 2040 (Nasdaq 2016).

Conclusion

Using the yearly production of 90 million vehicles and an average of 25 kg of copper per car, those statistics represented in 2013 10,2% of the world copper consumption of that year. According to the Bloomberg prognosis, 41 million electric vehicles will be produced in 2040, which would equal an increase of 1 to 2,2 Mt (or a 4,7% to 10,3% growth since 2013). Although the growth is spread over an period of 25 years and not all prognoses agree with it, it suggests that the rise of the electric car could become an significant event affecting the global market. This case study suggests that the rise of the electric car could become an indicator for future developments within the market and rises questions towards the consequences of other sustainable developments. This transition has the potential, when it perseveres, to be a major driver, next to conventional drivers such as global economic growth or growing prosperity. Which are all drivers, which can't be ignored.

CONCLUSION CASES DEMAND DRIVERS

Besides conventional drivers such as global economic growth or growing prosperity, the goal of energy efficiency and achieving a sustainable society will be an important force in the demand for copper. Those future consumption patterns indicate that demand will continue to drive and maybe even strengthen those commodity cycles.

7

7.1.3. Characteristics

Two characteristics identified in commodity cycles are the volatility and the relative extremes within a cycle. The following cases will show that the industry is trying to reduce the relative extremes within a cycle by stockpiling and releasing inventories (Case Inventories). Furthermore, the volatility is a consequence of the state of marginal costs within the industry, reflected in cost curves (Case Cost Curves).

Case Study: Inventories

Introduction

A factor that takes an important role in defining the characteristics of the commodity cycles are the inventories. The main use of inventories in this topic, is piling up metals in times of oversupply and releasing metals in times of deficits. This results in a easing effect on the metal prices (LME 2015).

Objective

To what extent have inventories an easing effect and how does this affect the time series of copper? Is there a difference between commercial and strategic inventories?

Commercial Inventories

The amount of metals stored is not very transparent, especially when the inventories are owned by a state. However, stock exchanges like COMEX and LME have inventories and their content are regularly published by the Chilean Committe Copper (Cochilco 2014). Figure 7.10 shows the yearly content of the inventories together with the copper price.
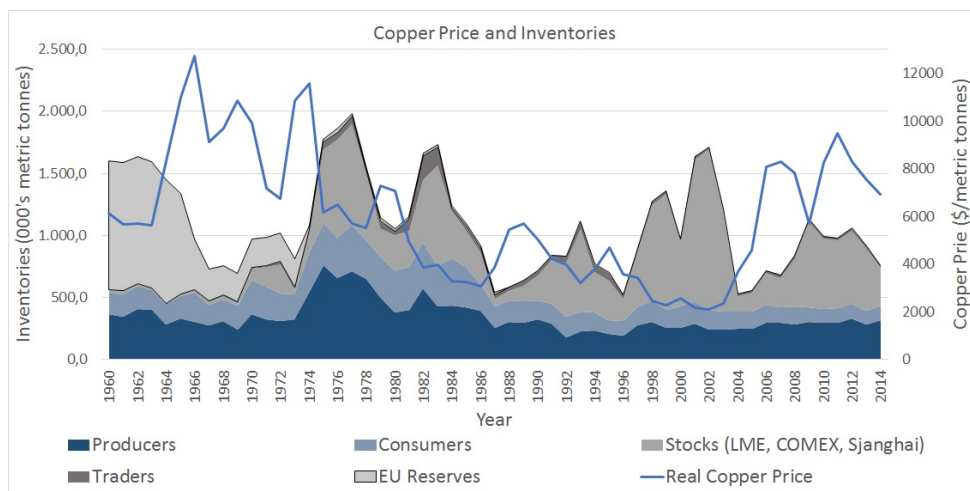
Figure 7.10: The content of several inventories is shown together with the copper price. (Cochilco 2014).

Referring to the two time series in figure 7.10, the dynamics of the relationship between the market and inventories can be reasoned. These dynamics are as follows: when demand increases, inventories are used to close the supply gap and when demand

decreases, inventories are used to store the oversupply. Figure 7.10 does not show an indication of maximization of profits, wherein the releasing of stockpiles is postponed until a certain high price level is reached. Instead of this, some moments can be recognized where the inventories drop, but the price does not increase much (in 2000). Or when the inventories continue to drop and the prices increase at the moment the inventories are almost exhausted (in 1986-1987 and in 2004). Therefore, the inventories are identified as an independent component in the value chain, driven by economic factors instead of strategic factors.

Figure 7.11 shows a basic model showing the relation of inventories towards supply and demand, which is based on the reasoned mechanism behind those inventories.
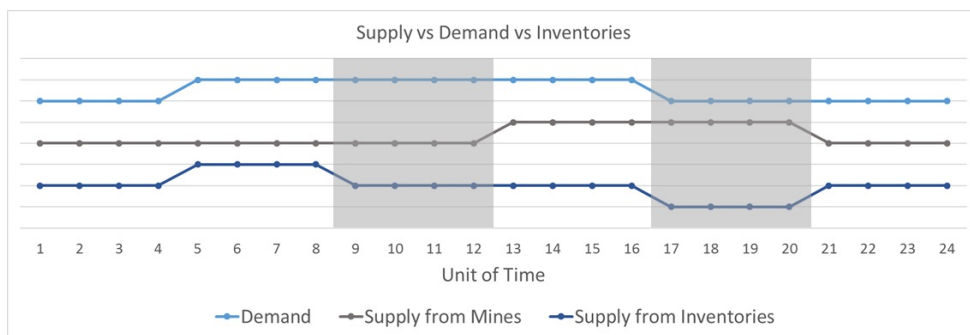
Figure 7.11: This figures shows relative time series of demand, supply from mines and supply from inventories, starting in a balanced system. At t=4, demand increases and due to delayed response of the supply from mines, a deficit occurs. This gap is initially filled by a supply from inventories. At t=8, the inventories become empty and a physical deficit occurs. As long as the supply from mines is not going up, the price will rise (t=9-12). From t=13, the system found a new balance. In the period t=17-20 the demand has decreased, the supply from mines continues, inventories are filled up again and the price rises. Ending in a newly balanced system.

Based on the time series and the reasoned dynamics, two hypotheses are defined, which will be tested afterwards:

1. Inventories are sold to close a sudden deficit. This postpones a (rapid) price rise until the storage in inventories reaches the bottom. This states that the inventories respond on a increasing demand, before the price does. The situations in 1986-1987 and 2004 do indicate this mechanism.
2. Decreasing demand causes an immediate oversupply and price fall. The oversupply is stored in the inventories. This states that the price responds on a decreasing demand, before or parallel to the response of the inventories.

Those two hypotheses will be tested and if the first hypothesis is true, an early warning indicator is identified.

To test the hypotheses, more detailed data was used in the form of monthly figures. This is smoothed by the moving average method. First hypothesis 1 was tested by checking,

if the marking point of every decline in inventories comes before the start of a price rise. This is shown in figure 7.12.
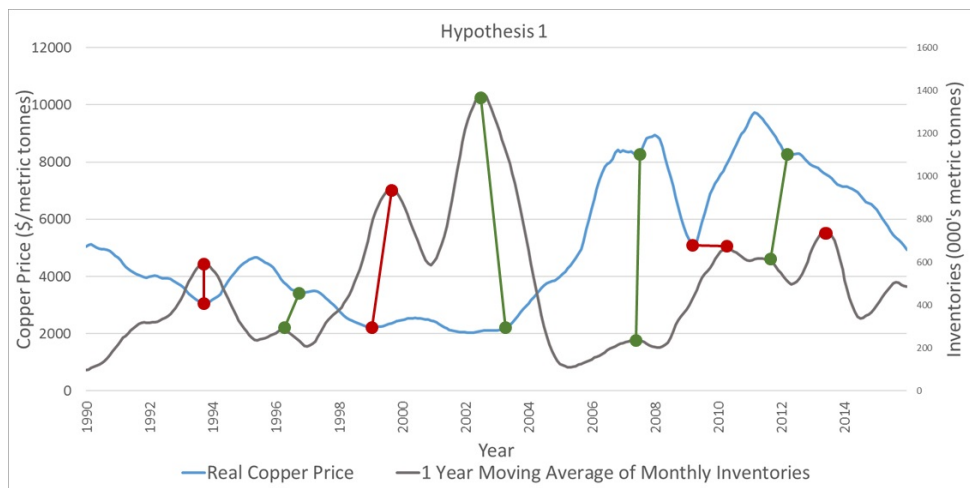
Figure 7.12: The starting point of a fall in inventories and the start of a price rise, caused by the same specific increase in demand, is connected. The line is coloured green, if it confirms the first hypothesis and it is coloured red if it does not (Cochilco 2014).

In half of the situations, hypothesis 1 is not valid. So based on this very limited data, the hypothesis is rejected. Decreasing the time span from one month to a week (if available) could improve the results and it could be likely that the conclusion would become different. However, the results show very different scenario's following a change in the content of inventories. So, these results show, that the content of inventories can not be used as an early warning indicator for sudden developments.

Next, hypothesis 2 was tested by checking if the marking points of every rise in inventories, is preceded or accompanied by the start of a price fall. This is shown in figure 7.13.
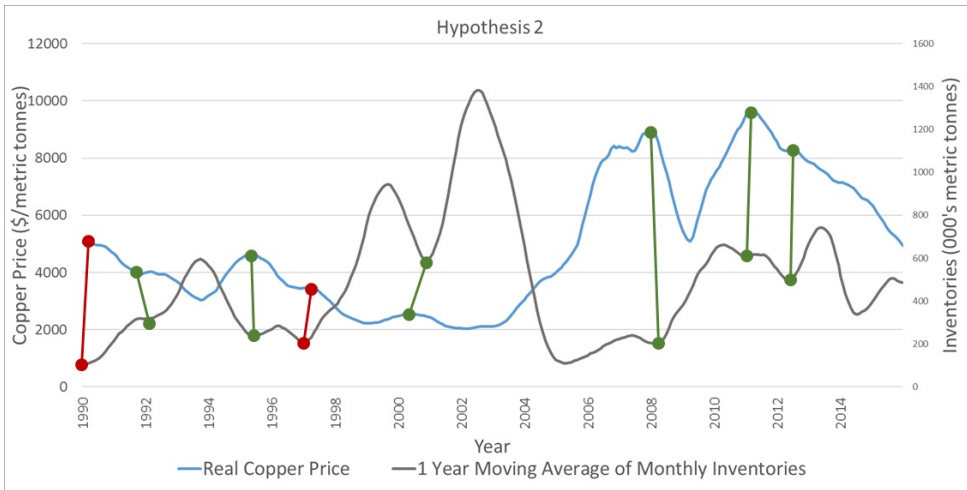
Figure 7.13: The starting point of a fall in price and the start of an increase in stockpiling, caused by the same specific increase of demand, is connected. The line is coloured green, if it confirms the second hypothesis and it is coloured red if it does not (Cochilco 2014).

The results show that hypothesis 2 is a more valid hypothesis. In the two occasions, which are not in line with the hypothesis, the time delay is still only minimal.

Strategic Inventories
Several sources state that the U.S. do not hold its own copper inventories since 1987 and do not have significant inventories since 1973 (Cochilco 2014, Perkins 1997).

Conclusions
Inventories are identified as independent components within the value chain. The sell of inventories does not depend on the price level, but instead, they are immediately released when a supply deficit occurs. Although there are clear relations between the content of inventories and the copper price, it seems less likely to derive clear rules out of it. Sudden drops or rises in the storage result in very different scenario's. Understanding interdependencies with other topics within this thesis could improve the understanding of the consequences of those sudden drops or rises.

CASE STUDY: COST CURVES

Introduction

A cost curve is a collection of the operating costs for all operating mines for a certain commodity. The mines are ranked in operational costs (vertical axis) and the horizontal axis represent the cumulative production figures. An example is shown in figure 7.14, in which Rio Tinto makes a prediction of where in the cost curve the Oyu Tolgoi mine will be located. The mine is ranked, based on 2016 numbers of costs of other mines and the predicted costs for the Oyu Tolgoi mine. The horizontal axes represents the cumulative production, and by taking a predicted production of 560 kt, the mine gets a relatively large area in the curve (Rio Tinto 2016*a*).
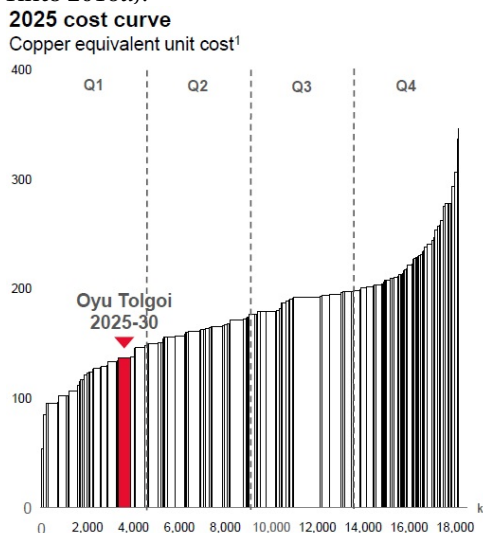
Figure 7.14: A cost curve made by Rio Tinto, in which they make a prediction of where in the cost curve the Oyu Tolgoi mine will be located. The mine is ranked, based on 2016 numbers of costs of other mines and the predicted costs for the Oyu Tolgoi mine. (Rio Tinto 2016*a*).

Due to a large total amount of mines and non-transparent information, a detailed analysis of cost curves has fallen out of scope. Therefore, this case will only focus on the concept of a cost curve.

Objective

In what way can the shape of a cost curve help to understand future price movements on the market?

Concept

In theory, supply and demand search for an equilibrium. If there is an oversupply, the price will fall, expensive mines become unfeasible and production will drop out of the

market. This occurs when the costs of mining are higher than the price of copper the company gets in return.
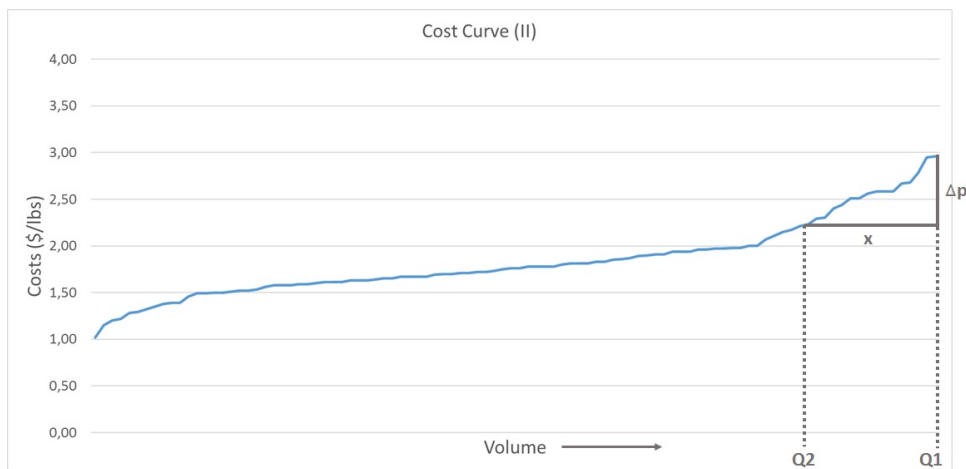
Figure 7.15: A cost curve is made to visualize the concept.

In figure 7.15 a generic cost curve is presented. To satisfy a demand of Q1, a volume of Q1 needs to be produced. This would only be achievable for a price of at least $3,50/lbs. If the demand falls to Q2, less production is needed. The price finds its equilibrium at $2,25/lbs and results in unfeasible expensive mines, which eventually drop out. Both rules apply all the time, and are the reason that the price continuously moves to an optimal price, in which an equilibrium of supply and demand is sustained.

The shape of the cost curve is quite important to understand price movements in the market. If the price difference between Q1 and Q2 is large, it indicates that a large price difference needs to be overcome to eliminate the production. This results in volatility. Examples of cost curves are shown in figures 7.16 and 7.17 (GFMS 2013, 2014, 2015, 2016). The figures show two comparisons of cost curves of two successive years. In both cases, the cost curve with a steeper ending occurred in a year with a relatively higher volatility.
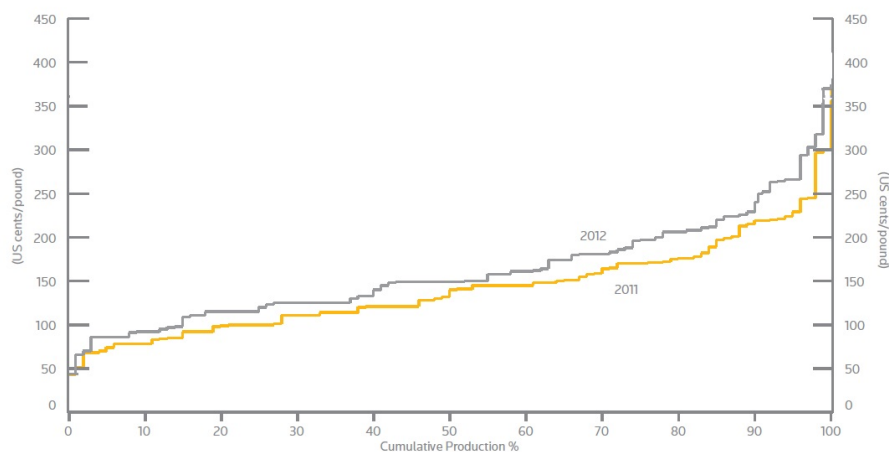
Figure 7.16: A cost curve is shown for 2011 and 2012. The price volatility in 2011 was 855 dollars and in 2012 it was 332. The steeper ending of 2011 is in line with the measured volatility (GFMS 2013, 2014, 2015, 2016).
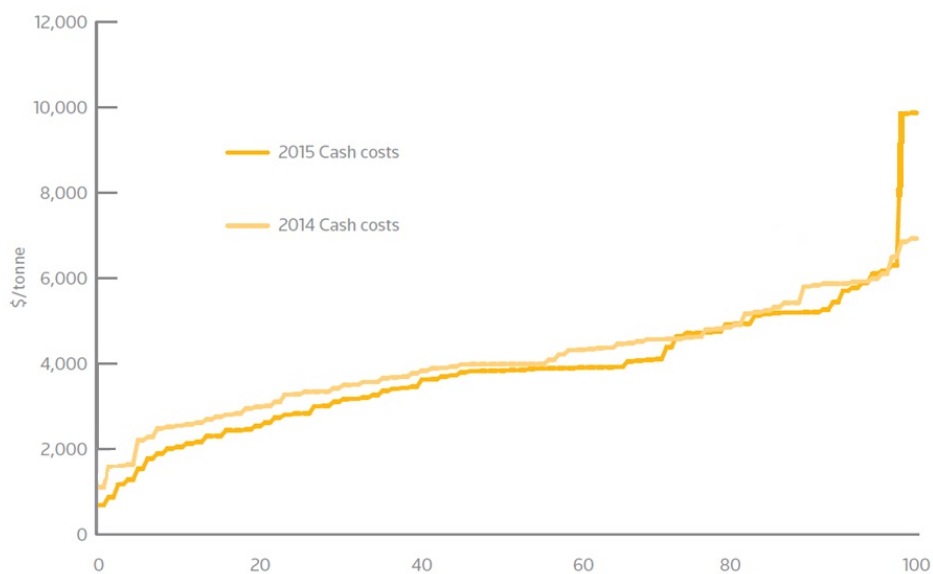
Figure 7.17: A cost curve is shown for 2014 and 2015. The price volatility in 2014 was 231 dollars and in 2015 it was 493. The steeper ending of 2011 is in line with the measured volatility (GFMS 2013, 2014, 2015, 2016).

An opposing argument that can be made on these curves, is the fact they do not indicate how demand develops within a year. Therefore, it is only possible to get an indication of the volatility relative to the previous years. Furthermore, one could also get an indication

of how the volatility would develop.

Some reasons can be stated to explain how the curve gets its form. One is the incentive to keep costs at a minimum. A sudden rise of the demand, would make this incentive less powerful and mines will prioritize in expanding their production. If the prices are stable, the incentive strengthens, companies will reduce their marginal costs and this results in a flattening of the curve's end.

Conclusion

The shape of the curve, and especially the curve's ending, is an indicator for the range of future price changes. A steep curve, would be an indicator for a period ahead with a relatively high volatility. On the opposite side, a relative flat curve, would be an indicator for a more stable market.

7

7.1.4. CONCLUSION

The commodity cycle is recognized as an ongoing search for a balance between supply and demand. Because of this, the basic drivers on supply and demand are identified. For the supply side only developments on a large scale affect the cycle. Industry wide events can influence the cycle from the supply side. For the demand side of the cycle, two non-conventional drivers are identified. The goal of energy efficiency and achieving a sustainable society will be an important force to continue and maybe even strengthen these commodity cycles.

The cost curves and inventories appear to be important indicators for the characteristics of the commodity cycle. The shape of the cost curve indicates the likelihood of volatility and the inventories can weaken the extremes of a cycle.

7

7.2. MARKETS

An often recurring theme in events affecting the copper industry are crises on the financial markets. This section will discuss how stock exchanges, the dollar and other commodities do affect the copper market.

7.2.1. FINANCIAL CRISES

Crises on the financial markets have caused periods of high uncertainty. The tendency that crises often take the copper markets down with themselves, makes this event an important indicator for the copper market (Nelson & Katzenstein 2014). Unfortunately, crises are unpredictable (Castellanos & Albizuri 2011) and the scope of this thesis is not to understand or to predict each of those crises. However, the crises share one big characteristic: uncertainty on the markets. This uncertainty can be expressed in the moving standard deviation of a market's time series and is generally high during financial crises. Important to keep in mind is that the standard deviation can also be high in prosperous times, due to a (rapid) growth of the economy for example.

In this section, the validity of the causality is checked, in which peaks and troughs in the copper market can be caused by peaks in the standard deviation of the S&P 500.

7

CASE STUDY: S&P 500

Introduction
The S&P 500 is the stock market index of the 500 largest companies listed on NYSE or NASDAQ. This thesis assumes that the volatility of this index represents the indicator for the sentiment about the global economy. The volatility can be defined as the moving standard deviation of the index (Investopedia 2016*k*). This calculation differs from the one used in the commonly used Volatility Index[1] (VIX). Due to the limited time range of the VIX, an alternative method is made and used in this case study (Investopedia 2016*j*).

Objective
Is the causality, that uncertainty on the markets affects the copper market, valid?

---

[1] The VIX is used as a tool to look forward on the markets. The volatility of a wide range of S&P 500 index options is used as indicator and is calculated from both calls and puts. The VIX origins from 1993 and was introduced by the Chicago Board Options Exchange (Investopedia 2016*j*).

Data

Figure 7.18 shows the stock market index of the S&P 500 and is corrected by inflation, as explained in chapter 2.3 (Yahoo Finance 2016). The one year moving standard deviation is calculated for the S&P 500 time series. This is visualized in figure 7.19, together with the real copper price.
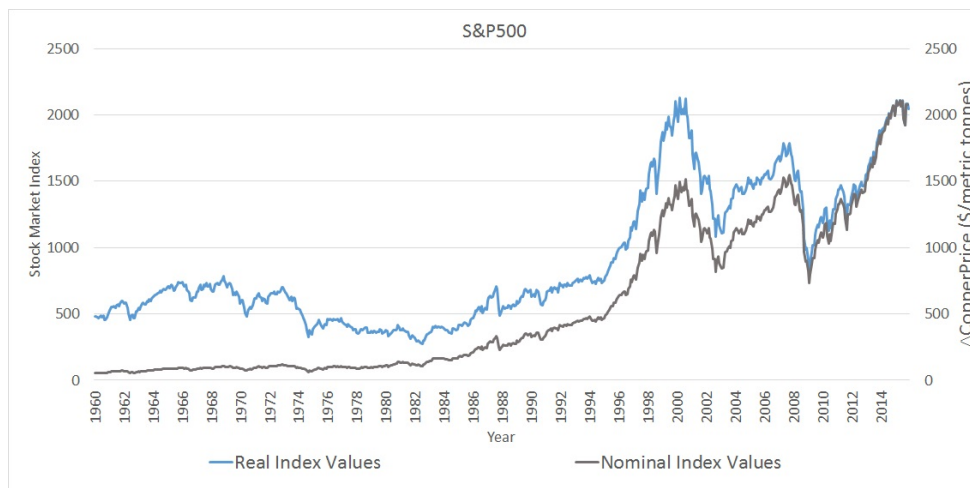
Figure 7.18: The stock market index of the S&P 500 and the copper price corrected by inflation (Yahoo Finance 2016).
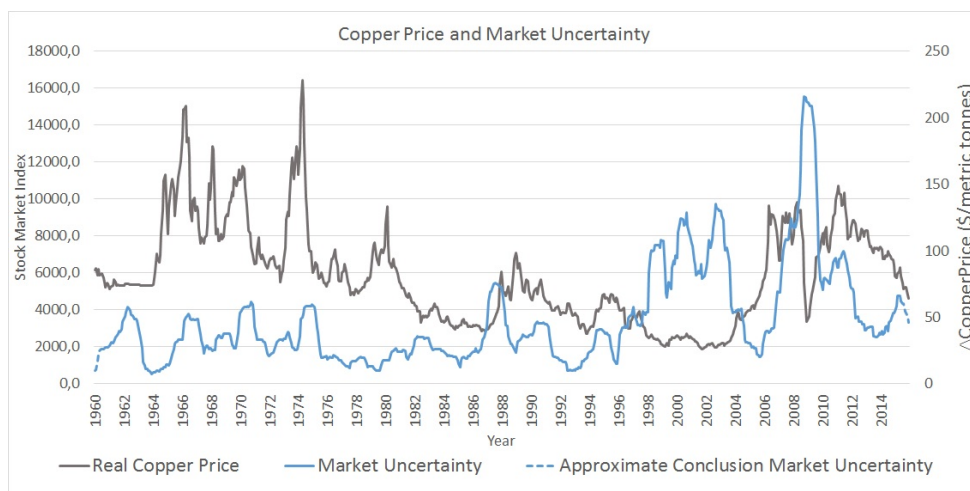
Figure 7.19: The moving standard deviation is calculated as indicator for the uncertainty on the markets. Besides the moving standard deviation, the copper price is shown as well.

Economic growth and decline result both in a higher deviation. So movements of the

copper price can be positively and also negatively correlated with the uncertainty on the markets. To determine the actual correlation between the uncertainty on the markets and the copper price, the one year moving average of the copper price is converted, relatively to the ten year moving average, to an absolute time series (equation 7.1).

$$\Delta P_t = \left| P_{1,t} - P_{10,t} \right| \tag{7.1}$$

P_t	= absolute difference between the one and ten year moving average
$P_{1,t}$	= one year moving average of the price
$P_{10,t}$	= ten year moving average of the price

The modification results in the following time series (figure 7.20):
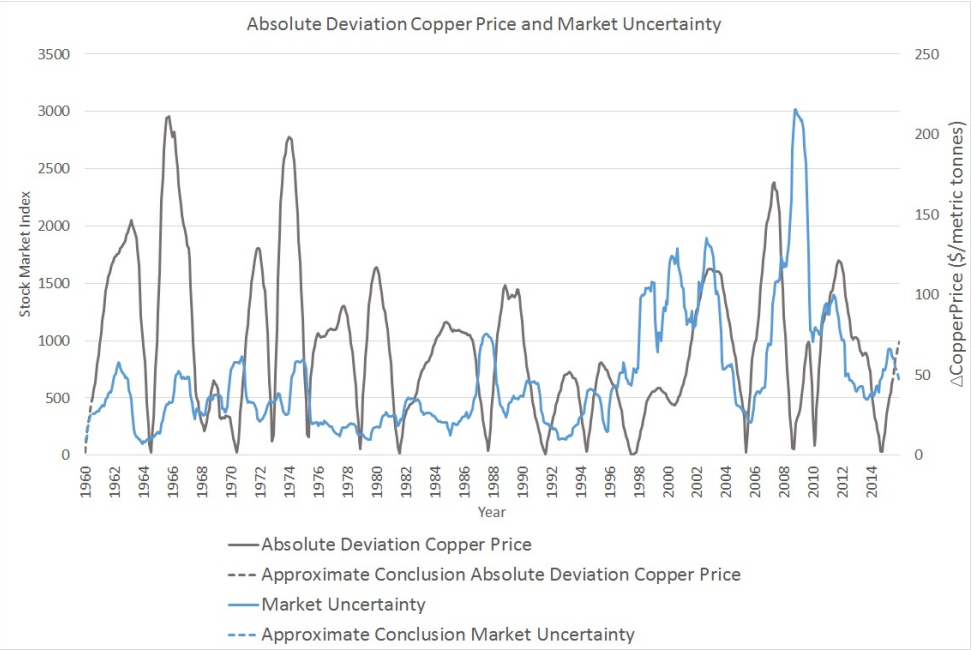
Figure 7.20: The uncertainty on the markets is shown together with the absolute differences between the one and ten year moving average of the copper price.

Interpretation

Taking figures 7.19 and 7.20 into account, it can be seen that the time series do not show similar behaviour. The correlation coefficients are only -0,1 and -0,025 for respectively figure 7.19 and 7.20. The conclusion can be derived that there is no correlation. However, one can identify a few occasions in which a downward copper price takes place during a period of a high uncertainty, mostly during U.S. recessions.
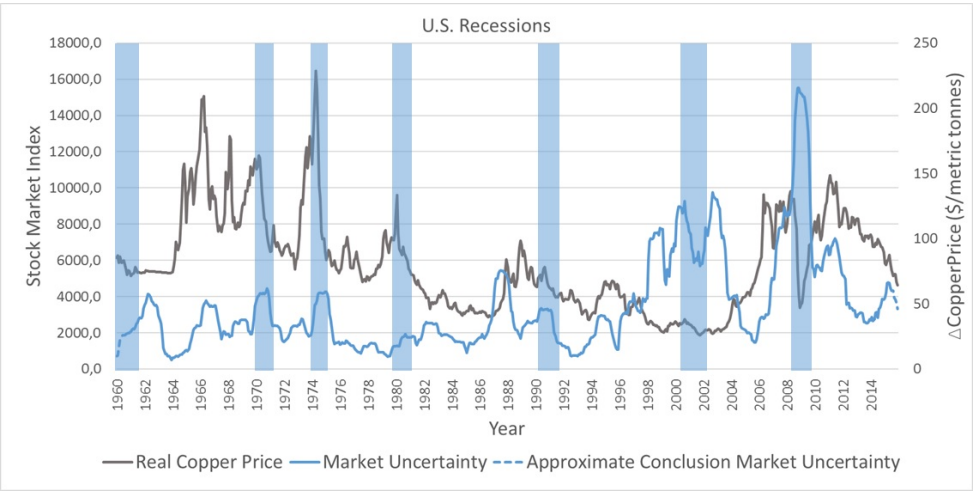
Figure 7.21: U.S. Recessions have occasionally caused a high uncertainty and falling copper prices.

As figure 7.21 shows, U.S. recessions have occasionally caused periods of high uncertainty. It is suggested by the USGS that this caused falling copper prices. This relation could indicate a cross correlation, a correlation with a time shift. The correlation coefficient is calculated for different time shifts, lags (in months). The time series for the market uncertainty is the series that is shifted relatively to the absolute copper price deviation. The results are shown in 7.22.
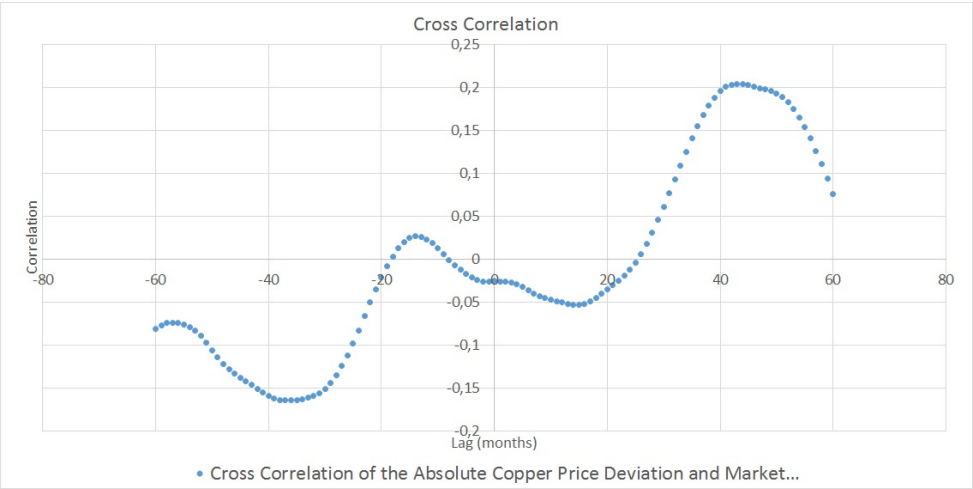
Figure 7.22: The correlation coefficient calculated for different lags of time shift. The time series for the market uncertainty is shifted l lags. A high correlation for negative lags, indicates a delay of the uncertainty. A high correlation for a shift in the positive directions indicates a price fall after an increase in uncertainty.

A high correlation for negative lags, indicates a delay of a deviation in uncertainty, relatively to a deviation in the copper price. A high correlation for a shift in the positive direction indicates a price rise or fall after an increase in uncertainty. However, the range of correlation coefficients is between -0,2 and 0,2, so there is no cross correlation present between the two time series.

Conclusion
A causality between the market uncertainty and the price movements of copper can't be defended by a correlation, or a cross correlation. However, events can be identified, in which a recession or other events causes a price fall. On the contrary, moments in which a price rise and a high market uncertainty both occur, are rare. The copper market can be affected by unpredictable financial crises, but the market has no further influence itself.

7

7.2.2. OTHER MARKETS

To identify possible indicators in other markets, four markets were selected, which all reflect a different relation towards copper.

- **Base Metal:** As a metal in the same metal group as copper.
- **Oil:** As a big contributor to the marginal costs of the production of copper.
- **U.S. Dollar Currency Index:** The relation of copper with the dollar, as trade currency.
- **Gold:** This fourth commodity does reflect more the influence of political risks, instead of its relation as commodity to commodity. Therefore it is not discussed in this section, but in section 7.6.1.3.

Their relation is checked and possible indicators are identified.

CASE STUDY: OIL CORRELATION
Introduction
It is often mentioned that oil and copper are highly correlated and that high oil prices are a cause for high copper prices (ABN Amro 2014). This is due to the consumption of energy in the extraction and processing of copper ore. When oil prices are high, energy prices are high and so are the costs. This pushes the copper prices upwards.

Objective
How high is the impact of the causality made and is the statement of a high correlation correct?

Data
A time series was created for the marginal costs of copper (Mikesell 1979, Wood Mackenzie, Bloomberg and AllianceBernstein 2015, Thompson 1993, USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013). Figure 7.23 shows the marginal costs together with the copper price. The trends of the ten year moving average of the copper price and the marginal costs follow each other with a correlation of 0,88.
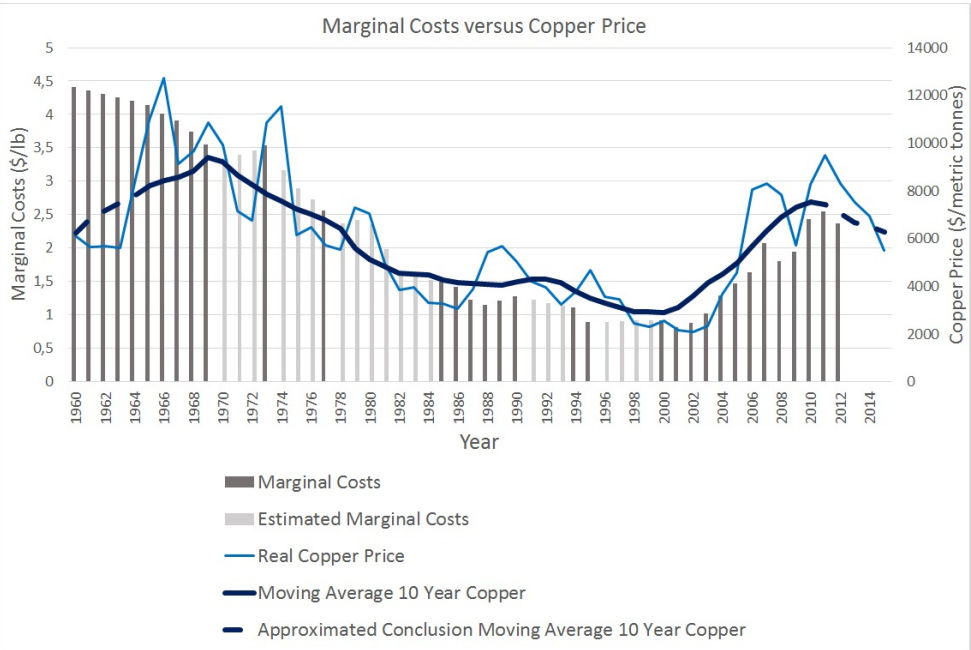
Figure 7.23: Marginal costs versus the copper price (Mikesell 1979, Wood Mackenzie, Bloomberg and Alliance-Bernstein 2015, Thompson 1993, USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013, Index Mundi 2016*b*, Macrotrends 2016*a*).

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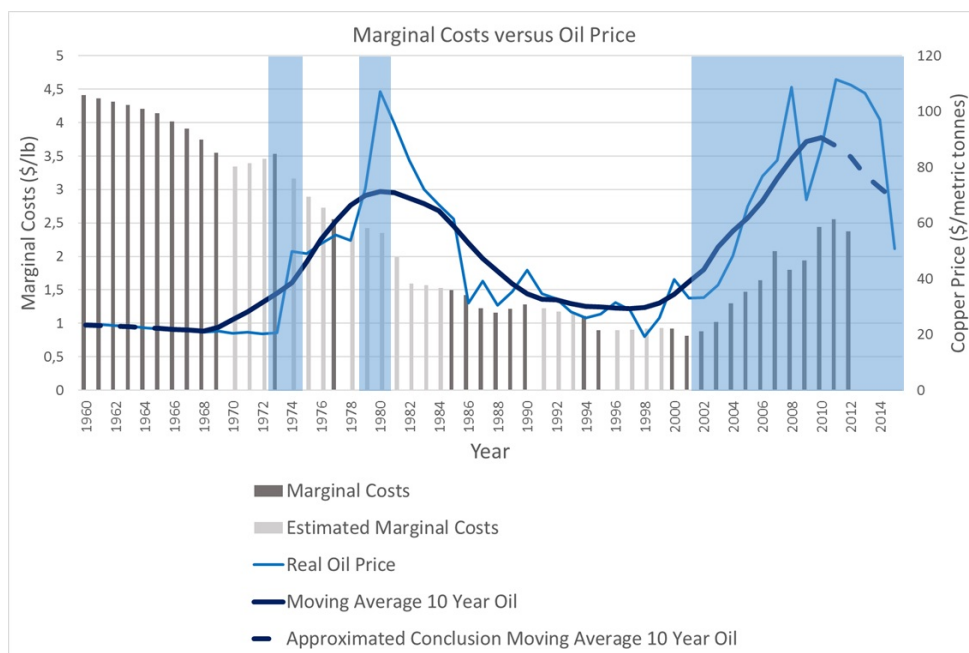
Figure 7.24: Marginal costs versus oil price (Mikesell 1979, Wood Mackenzie, Bloomberg and AllianceBernstein 2015, Thompson 1993, USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013, Index Mundi 2016*b*, Macrotrends 2016*a*).

Figure 7.24 shows a graph of the marginal costs and the ten year moving average of the oil price. The power of controlling the oil pricing shifted in the early 70's towards OPEC and the U.S. was not able to keep an upper limit to the price. Because of this the period 1960-1972 is ignored in the correlation. The correlation between the marginal costs and the oil prices in the period 1973-2012 was 0,48.

Interpretation
Overall the marginal costs show one trend: downwards. However, three periods are recognized in which the trend is (slightly) broken: 1973-1974, 1979-1980 and the 2000's. And all these periods took place at the same time as respectively the 1973 Oil Crisis, the 2nd Oil Shock and the 2000's commodity's supercycle. All three periods represented a period of an extreme acceleration of the oil price upwards.

The causality made suggests that the marginal costs follows the trend of the oil price. The copper price follows in turn the marginal costs. These last two factors would search for a balance in a free market, because production below the costs is not feasible and selling far above the costs seems unlikely in a competitive market. So this part of the causality seems valid. The relation between the marginal costs and the oil price can be

substantiated by reasoning that an increase in costs would cause a decrease in supply. Because of this, the demand can't be met and the price increases.

Discussion

Using this method, several more factors can be shown to have an influence on the price. This suggests a more complex situation and the strength of the consequences of the correlation between the oil price and marginal costs is therefore a topic for discussion. Other factors are:

- Improvement of the processing technology (Wills & Atkinson 1991): this seems to has an enormous impact over the period 1960-2000. It has decreased the marginal costs in 2000 to 1/4th of the level in 1960.

- Increase in Chinese demand: After the year 2000 costs rapidly grew. This could have been caused by an increase in the demand for all commodities, including copper. Due to the high prices, the incentive or practicability, to keep the costs as low as possible, is reduced and so the level of low marginal costs is not maintained (Tilton 2014).

- Other explanations for the increase in marginal costs for the period 1972-1976 are mentioned as well (Mikesell 1979). Besides heavy increase in energy prices, the price of supplies increased with 45%, the hourly wages increased with 45%, the operations became less productive and an increase in awareness for pollution caused new (expensive) requirements for mines to reduce the pollution.

Besides the marginal costs, the copper and oil markets can both be influenced by the occurrence of events. By overlapping the copper and oil time series, trends can be compared. And by applying a moving correlation, the correlation at a certain moment in time can be determined. The result is shown in figure 7.25.
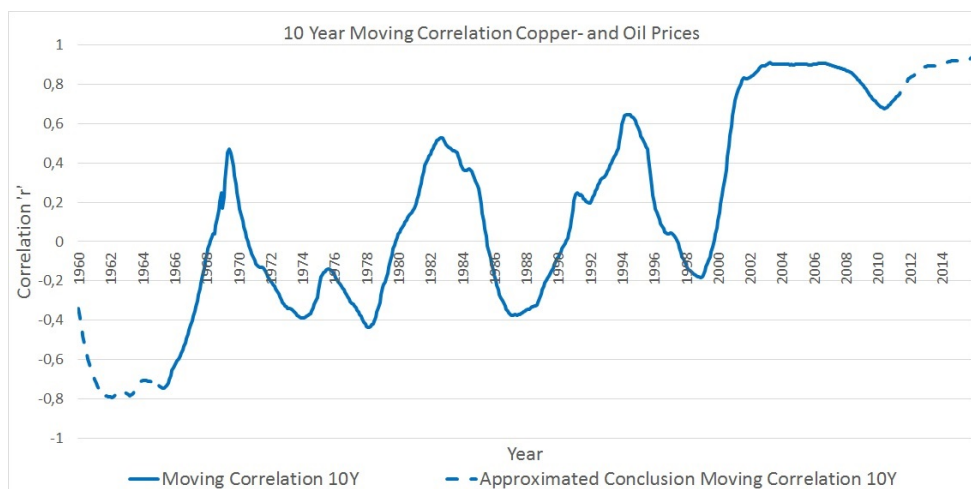
Figure 7.25: Moving correlation copper and oil Prices.

Based on this data, it can be said that in the period 1960-2000, the copper and oil markets were influenced by mostly different events. The rise of China and the following increase in demand has influenced both markets in a similar way. In this case the two markets had a high correlation caused by a third component.

Conclusion

It seems that extreme oil prices have caused an influence on the marginal costs. But the effects are exaggerated. An improvement in processing technology, or the increase in Chinese demand have caused far more extreme consequences to the marginal cost of copper. Besides this, the correlation between the copper and oil prices is not convincing. The price movements are caused by different sets of events and only in the last 15 years there is an overlap in causes for both price movements. Therefore, the oil market is not a good indicator for the copper market. However, a critical consideration of the oil market, can help to understand what happens or can happen to the copper market.

7

Introduction

Copper is considered a member of the base metals, a group of inexpensive metals, which are widely used in the world. Other examples are lead, zinc and nickel. Main applications can be found in respectively the battery industry, steel galvanizing and the strengthening of stainless steel (USGS 2016). All base metals are subject to big events, causing similar trends in the time series, this is confirmed in figure 7.26. However, the time series are disturbed by events, causing unique consequences to a specific metal (USGS 2010*b*, Index Mundi 2016*a*). Examples are a boom in the battery industry or the dissolution of the Soviet Union, causing respectively an increase in demand for lead and rise in Nickel export from Russia (USGS 2010*b*).
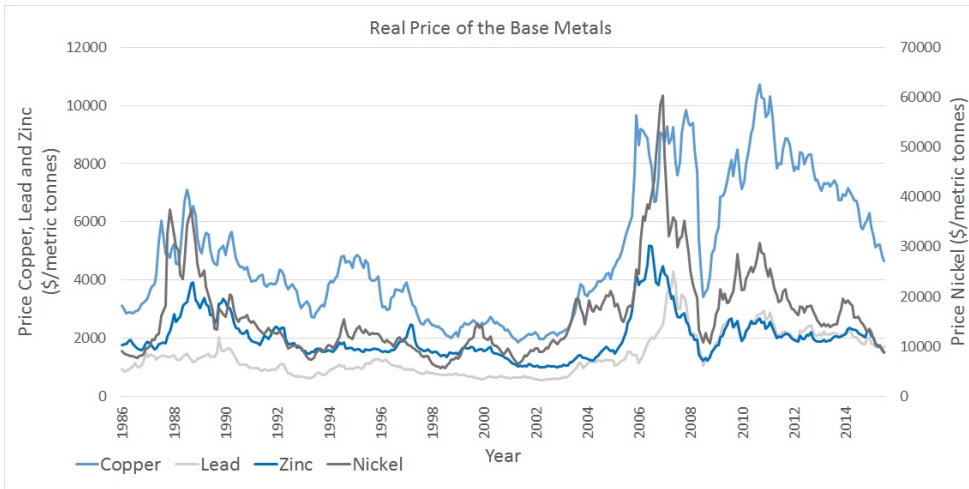
Figure 7.26: Similar trends can be identified for all events. However, they are strongly disturbed by events causing specific consequences to a specific metal (Index Mundi 2016*a*).

The base metals share time series, formed by similar events and are all used in common applications. From this, the following objective can be derived.

Objective

Can developments in the markets of other base metals indicate upcoming movements in the copper market? Can developments in other markets improve the understanding of causalities in the copper market?

Data

First the correlation of the copper market with other markets. As figure 7.26 shows, all metals show similar long term trends. This is emphasized by the correlation between

copper and the others, which is between 0,70 and 0,90 and is quite high. By calculating a cross correlation[1], it can be checked if the correlation rises when the time series are shifted relatively to each other. If so, an early warning indicator would be identified. The results of the cross correlation are shown in figure 7.27. As can be noted, the highest correlation is present, if the time series are not shifted relatively to each other. This indicates that all three base metals react within similar speeds on events. Besides the cross correlation, a deeper focus is given on all events that cause all movements on the time series. Unfortunately not many similarities can be identified, apart from the demand and economy related categories (section 2.1.2).
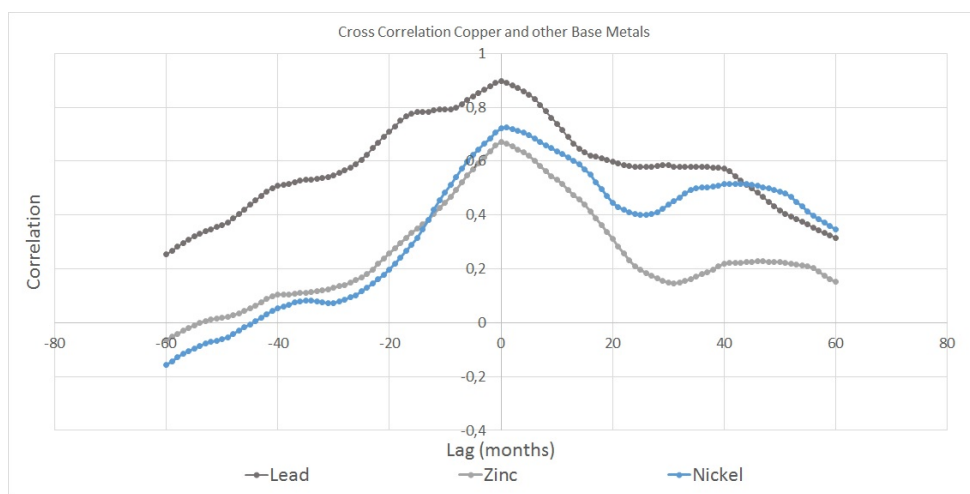
Figure 7.27: The correlation coefficient is calculated for different lags of time shift. The time series for the market uncertainty is shifted x lags. A high correlation for negative lags, indicates a delay of the non copper series. A high correlation in the positive directions indicates a delayed reaction of the copper market (Index Mundi 2016*a*).

Conclusion
The markets for base metals do not provide new insights on the copper market, neither do they provide an predictive function.

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[1] As discussed in section 7.2.1 the time series for the non copper market is shifted relatively to the absolute copper price deviation. A high correlation for negative lags indicates a delay of a change in the non copper series, relatively to a change in the copper price. A high correlation for a shift in the positive direction indicates a price rise or fall after a change in the non-copper series. If the last is the case, an early warning indicator could have been identified.

CASE STUDY: U.S. DOLLAR CURRENCY INDEX CORRELATION

Introduction

As the dollar is the trade currency, it has an inverse relation with the commodity prices (Gilbert 1989). The main reason for this is that as the value is low, it takes more dollars to buy an equal amount. Secondly, as the dollar strengthens, commodities become more expensive in non-dollar currencies. This has in general a negative effect on demand. The same applies to a weakening dollar, which has a positive effect on demand (About Money 2016). Because of this relation, the strength of the U.S. Dollar Currency Index (USDX) is often used as a cause for high or low commodity prices. The U.S. Dollar Currency Index (USDX) is a weighted averaged value, relative to other selected currencies such as the euro (weight = 57,6%), Japanese yen (13,6%), pound sterling (11,9%), Canadian dollar (9,1%), Swedish krona (4,2%) and Swiss franc (3,6%). A more detailed focus on these figures shows that the correlation is high and, as stated before, negative. Because the exchange rate of several currencies is included, the system is quite balanced and there are no time delays present. This is emphasized in figure 7.28(Investing.com 2016).
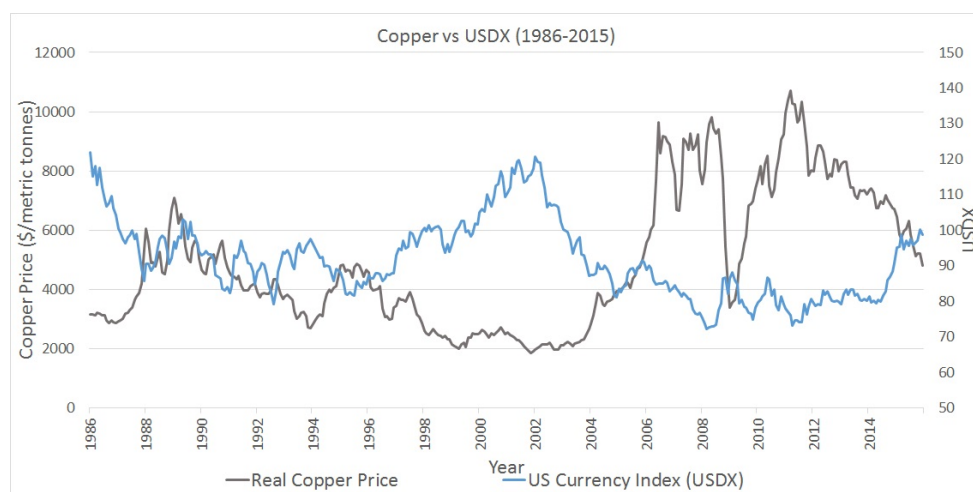
Figure 7.28: A more detailed focus on the copper prices and the USDX shows that the correlation is high and negative. Because the exchange rate of several currencies is included, the system is quite balanced and there are no time delays present (Investing.com 2016).

In general, a strong dollar means that other currencies are weak. But this strength is measured relatively to its most significant trading partners.

As an indicator

Because the copper price and the USDX show in general similar, but inverse, behaviour, the USDX offers an wider view on the copper market. Events, which share no relation with the copper market, but do affect the USDX significantly, become suddenly contributing factors to the copper price. Particularly events which affect the the dollar

directly. But due to the large share of the euro, yen and pound sterling in the USDX, Internal events in the EU, Japan or the UK could be significant as well.

7

7.2.3. CONCLUSION

The influence of market uncertainty on the copper market is expressed in the form of unpredictable financial crises, but has no further influence.

Similar markets like oil or base metals play a role, but the effects are exaggerated. The markets for base metals do not provide new insights on the copper market, neither do they provide a predictive function. The situation for oil is similar. However, due to its relation with the marginal costs of copper production, there is a weak relation visible. In history, high oil prices did not impact the copper price significantly, but recently both marginal costs and copper and oil prices did rise. This trend break could be explained by oil's influence on the marginal cost, but also by other reasons, such as the growth of Chinese demand for copper and oil. The future will tell what the precise role of oil is in recent developments.

Exchange rates seem to be a market instrument which indicates the market circumstance best. A very high negative correlation with the U.S. dollar is present and this plays a significant role in the commodity cycles.

7

7.3. ECONOMIC BOOM

7.3.1. INTRODUCTION

An economic boom is marked as a period with a rapid increase of GDP, caused by a significant output within a population. Furthermore, there is an increase in demand, wages, productivity and sales (Business Dictionary 2015, Investopedia 2015*a*). Real economic growth occurs when a nation has the ability to minimize its cost throughout the whole value chain and to maximize the value of the goods and services it produces (Investopedia 2015*b*). To create an economic boom, a nation needs to be able to increase the standard of living of their population. People need to want access to electricity, to live in cities and to use more energy. This section will take some important indicators, will identify historical precedents and will determine the potential of similar booms in the future. This is done by identifying four groups in the world, each of a similar size, but in a different stage of development, which are used in every case study.

1. China, which is currently undergoing an economic boom and has a population of 1.36 billion people (The World Bank 2014*f*). After a long period of almost 30 years, wherein China implemented free-market principles, China has finally experienced in the early 2000's an enormous growth in output (The World Bank 2014*d*, The Guardian 2010).

2. The Organisation for Econonomic Co-operation and Development (OECD), among the member states are the North American nations, the members of the European Union, Australia, New Zealand, Japan and Korea (OECD 2016). As can be seen in figure 7.29 those represent a major part of the developed countries in the world. This is based on the gross domestic product (GDP) (The World Bank 2014*a*). In this section the OECD nations represent the developed part of the world and have a population of 1.27 billion people (The World Bank 2014*f*).

3. The third group is represented by India, which has the second largest population of 1.30 billion people. India embraced the free-market principles only 25 years ago (compared to the 30+ years of China) and since then, the rest of the world had high hopes for an economic boom in India. So far, India has stayed far behind China and did not meet the expectations. However, recently India is experiencing the highest economic growth in the world, which makes India an interesting developing region (McKinsey 2016*a*).

4. Sub-Saharan Africa is one of the most underdeveloped regions and has a population of 0.97 billion people. As the case study in this section will show, the Sub-Saharan region come off very low for most indicators. During the last decade, African nations are more and more implementing free-market principles in their society. Consequently, the region underwent economic growth, which did not only originate from the resource boom, but from widespread sectors. The region consists of many nations which are facing many challenges, such as wars, natural disasters or different growth paths (McKinsey 2010). Because of this, the Sub-Saharan region will face a complex growth with a lot of potential.

GDP per capita, PPP (current international $)
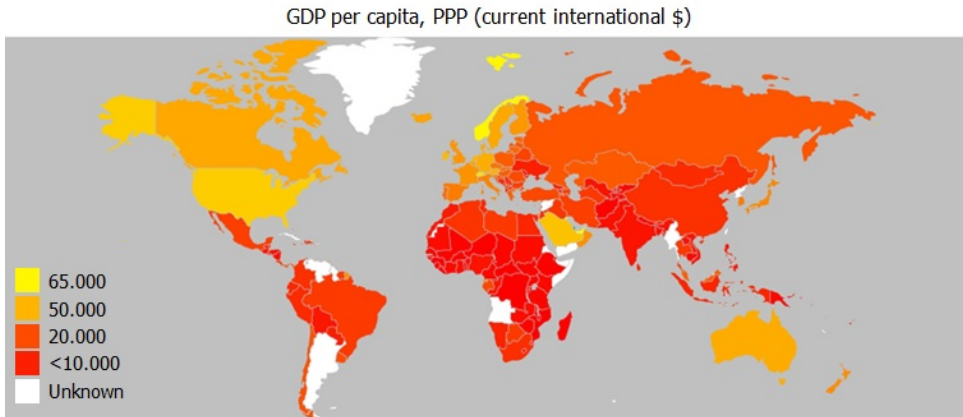
Figure 7.29: The gross domestic product (GDP) per Capita in current US$ in 2014. The purchasing power parity is included in these figures (see next paragraph). Based on this indicator, the main part of the world is underdeveloped. The most developed nations are located in North America and Europe and are part of the OECD (The World Bank 2004, 2012, 2014*b*).

Besides this list, there are many other nations/regions, which could undergo an economic boom. The significance of such, is dependent on the strength of the growth and the population within this nation/region. This thesis will discuss the impact of an economic boom and does not further discuss the likelihood of these economic booms.

7.3.2. DEFINITIONS

Next, three themes need to be explained, which will be occasionally readdressed in this chapter:

- **Gross Domestic Product (GDP)**: The total value of all domestically finished goods and services. It is often used as an indicator for the economy (Investopedia 2016*c*).
- **Purchasing power parity (PPP)**: An adjustment, to compensate for the purchasing power, which has to be made on the exchange rate. A foreign nation's currency is exchanged to an international dollar. This is a factor which is specific for the cited nation. For one international dollar, a comparable amount of goods and services can be bought as for one U.S. dollar. The ratio between the international dollar and the U.S. dollar is the PPP for the specific nation (Investopedia 2016*h*, The World Bank 2016). A simplified version of the PPP is the 'Big Mac Index'. In this index all global prices for a Big Mac are compared in U.S. dollars. Exchanged in U.S. dollars, a Big Mac in Norway, does not cost necessarily the same in dollars (Economist 2011).
- **Postwar Economic Boom**: After World War II, the economies of the OECD members grew continually for two decades. An average growth of 4% in the 1950's and near 5% in the succeeding decade. After a few big events in the early seventies, such as the oil-crisis and the 1973-1975 recession, the grew fell back to an average of 2 to 3%. This is considered the end of the postwar economic boom. (Marglin &

Schor 1990, The World Bank 2014*a*).

This section will continue to verify and explain how the gross domestic product is a driver for the demand for copper. It will conclude by discussing the actual relation between the GDP and the copper use per capita and subsequently the potential of ongoing development in China and India.

7.3.3. DEMAND DRIVERS

Growth in GDP in itself is not a sufficient indicator for an increase in the demand for copper. A causality can indirectly be made, but therefore, an intermediate step from another indicator is required. To identify these indicators, the following criteria need to be satisfied:

- **Requirement 1**: Economic growth is accompanied or preceded by this indicator. Therefore, a form of correlation between the indicator and the GDP needs to be present.
- **Requirement 2**: A causality can be derived between the indicator and an increase in demand for at least one of the five categories of end uses of copper. Those five categories are as follows:
  - Building construction
  - Electrical and electronic products
  - Industrial machinery and equipment
  - Transportation equipment
  - Consumer and general products

  Those categories are discussed and explained in more detail in section 2.2.2.

Four indicators are identified which might have significant impact: energy use, electricity access, urbanization and high technology exports. In the following cases, those four indicators are tested for both requirements. The potential impact of this indicator is measured for each of all three groups.

CASE STUDY: ENERGY USE

Introduction

The use of energy is reflected by the primary energy in kg of oil per capita, which eventually will be used in all facets of society (The World Bank 2004, 2012*b*).

Requirement 1

A form of correlation between the use of energy and the growth of the GDP can be seen in figure 7.30. An increase in GDP results in an upward trend in the use of energy. Some extreme outliers can be recognized in figure 7.30. There are various of explanations for these outliers. Such reasons are the desalination of water in Qatar (18800 kg of oil equivalent per capita) and aluminium production in Iceland, which is very cheap, because of the hydro energy in Iceland (17800 kg of oil equivalent per capita) (Oilprice.com 2014, The Independent Icelandic and Northern Energy Portal 2016).

Figure 7.30: The energy use of 125 countries is plotted versus the GDP per capita, PPP. The red dots represent Sub-Saharan Africa (I), India (II), China (III) and an average for the OECD members (IV). The blueish area is made by the author and covers at least 90% of the plotted countries. As the GDP increases, an upward trend in the use of energy can be recognized (The World Bank 2004, 2012, 2014*b*,,).

Figure 7.31 shows the growth of the energy use in historical context. Both Chinese and the postwar economic boom are clearly visible in the figure. India and Sub-Saharan Africa show only an almost negligible increase (The World Bank 2004, 2012*b*). After the postwar economic boom, the economy of the OECD members became more mature and grew less rapidly. Causes for a mature economy are a more stabilized population and fully built infrastructure (Investopedia 2016*f*).
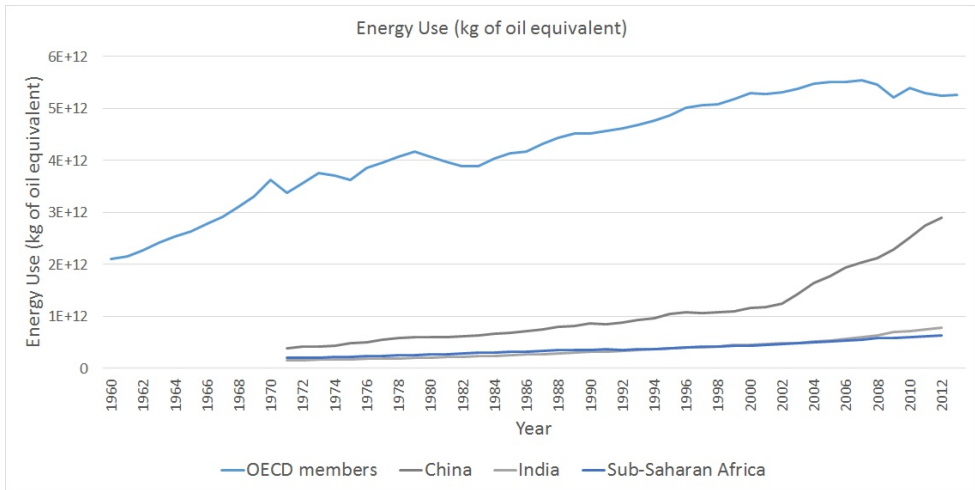
Figure 7.31: A time series of the energy use is shown for India, China, OECD members and Sub-Saharan Africa. A rapid growth is visible for the OECD members in the sixties and for China in the 2000's (The World Bank 2004, 2012*b*).

Requirement 2

Energy use, as an indicator for an increase in demand for the end uses of copper, is important, because it covers all facets of the economy. The same goes for the five categories of copper. An increase in building or the use of electrical and consumer products, industrial machinery and transportation results in the use of more energy. Based on this logic, an increase in the use of energy follows an increase of use in copper. However, if a nation shows all signs for ongoing development, an increase in copper demand can be predicted by reasoning backwards in this chain of events. For example: a nation undergoes an economic boom and the people want to use more luxurious products. More energy will be transported and consumed and consequently, more copper is used in electric cables and conductors.

Potential

Determining the potential of developments, caused by China or India, can't be done by simple extrapolates. Although figure 7.30 shows an upward trend, it does not show the historic trend of this slope. In figure 7.32 the data of 2004 is added. As can be seen, the slope has gone down significantly in 8 years. This is due to successful investments and policies, made by the OECD members. Also China and India have made efforts to improve their energy efficiency (International Energy Agency 2015).
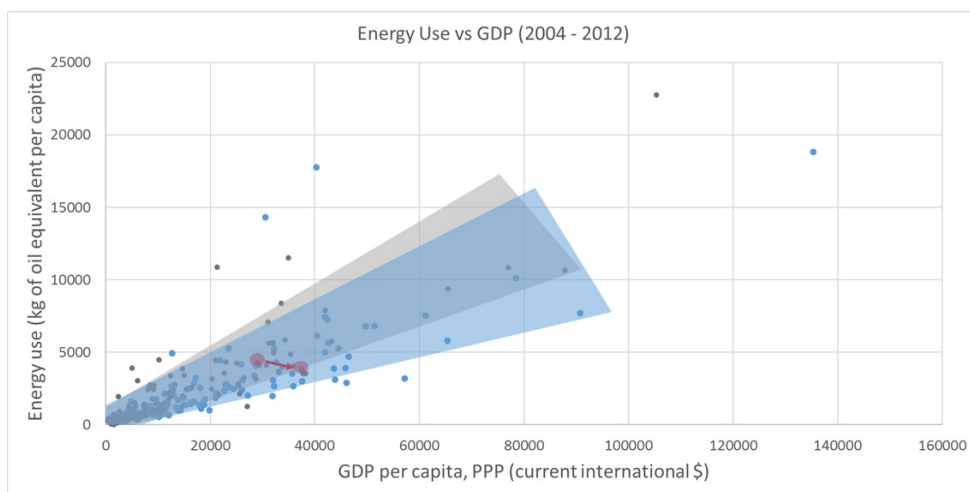
Figure 7.32: Although figure 7.30 shows a trend line going upward, it does not show the historic trend of this slope. In this figure data for 2004 is added. As can be recognized, the slope has going down significantly for 8 years. (The World Bank 2004, 2012, 2014*b*,,).

Ongoing developments and efforts to increase energy efficiency make it likely that a Chinese, Indian or Sub-Sahara African increase in GDP, will have less affect on the growth in used energy. However, India has still a very low GDP and a low energy consumption and also China does not meet the current OECD levels. For copper it means that there is a lot of potential for an increase in the use of copper. As the metal with the highest electrical conductivity (section 7.4.1.3), after and before the precious and expensive metals silver and gold, copper plays a key role in achieving the energy efficiency goals (Copper Development Association Inc. 1999*b*), as discussed in section 7.1.2.

Finally, the transition to a mature economy. China has passed through its own economic boom and currently the relative growth is decreasing. Futhermore, is China facing a contracting population. This could result in an decreasing incentive for creating jobs and an approaching transition to a more mature economy. On the other hand, India and Sub-Saharan Africa are still underdeveloped with a growing population and could therefore enter a phase of rapid development (CIA 2016*b*,*a*).

Conclusion
China has shown in the last decade a tremendous growth, similar to the postwar economic boom. If the OECD example is followed, China would enter a more mature phase, accompanied by a slower growth in the use of energy consuming products. The global collective efforts for the efficient use of energy can weaken the upward trend of GDP and energy use. However, copper plays a key role in this drive for energy efficiency (section 7.1.2) (Copper Development Association Inc. 1999*b*).

On the opposite side of China and the OECD members, a major part of the global population is represented by India and Sub-Saharan Africa. Still underdeveloped, it gives the potential to India and Sub-Saharan Africa to create an increase in demand for copper, when it may undergo their own economic boom (The World Bank 2004, 2012*b*).

7

Introduction

The percentage of a population, that has access to electricity and the GDP is compared. Following is the impact and potential impact on the copper market assessed.

Requirement 1

Figure 7.33 shows how access to electricity and GDP are correlated. It is noteworthy that the rapid rise in population with access to electricity, as the GDP per capita increases. This, and the fact that the access to electricity is essential for most everyday used products in a more developed nation, makes the access to electricity a basic need.

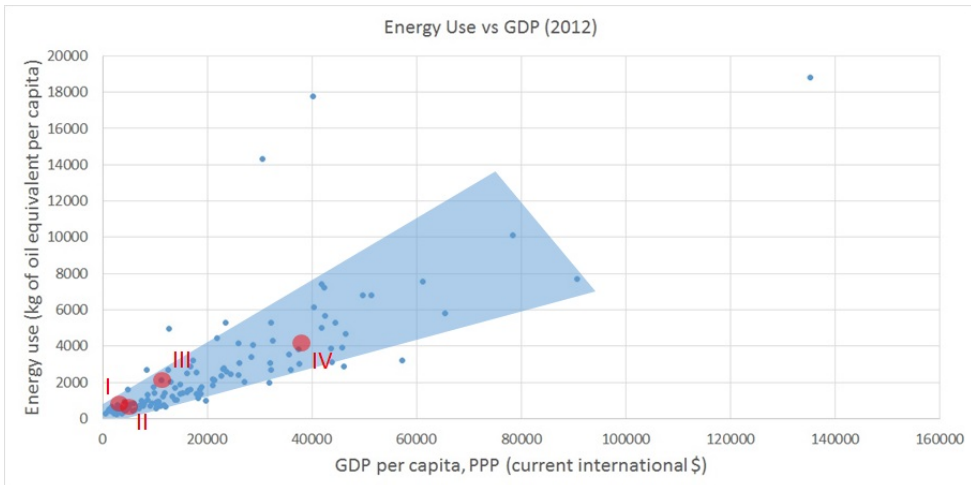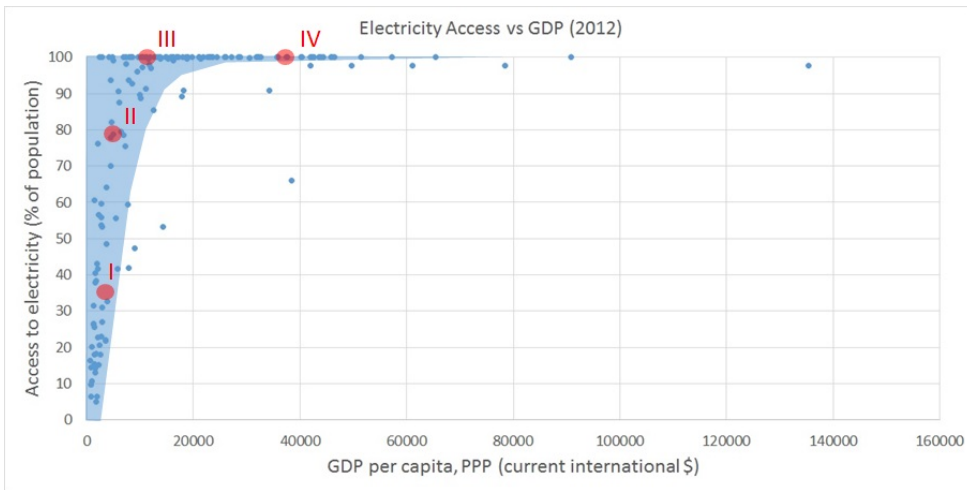Figure 7.33: The percentage of population, which has acces to electricity of 158 countries is plotted versus the GDP per capita, PPP. The red dots represent Sub-Saharan Africa (I), India (II), China (III) and an average for the OECD members (IV). The blueish area is made by the author and covers at least 90% of the plotted countries. The percentage of population, with access to electricity rises rapidly, whereas the GDP only has to increase slowly (The World Bank 2012*a*).

Notable is China's current status with 100% of its population with access to electricity. India stays slightly behind with 80%. In Sub-Saharan Africa however, only 35% of the people has access to electricity. All three figures fit in the main trend of increasing access, as the GDP per capita rises.

Requirement 2

Copper is considered to be the metal with the highest electrical conductivity, after the precious (and more expensive) metal silver. Although aluminium and gold are a compatible substitute (section 7.4.1.3) as respectively more inexpensive or non corroding metals, copper's complete set of characteristics (high electrical and thermal conductivity and inexpensive), give an advantage to be used as metal for electric cords (Siemens 2014,

Geology.com 2016, Copper Development Association Inc. 1999*a*). Therefore, laying an electricity network has a direct impact on the copper market.

Potential

As figure 7.33 emphasizes, the potential impact of the construction of new electricity networks on the demand for copper has reduced. The complete population of China is nowadays connected and India is 80% connected. Sub-Saharan Africa however, is only 35% connected, which indicates that this region does not have the full basic needs yet (The World Bank 2012*a*). The construction of new networks will become less, but still roughly a billion people (0.15% worldwide) lack a connection to electricity. Building those networks and maintaining others, will require a continuous demand for copper.

Conclusion

The global status of electricity networks, in which 85% of the population is connected to electricity, suggest this indicator has lost most of its strength, but still one billion people are not connected. The construction of new networks would cause a less significant impact on the demand for copper over time. This also depends on which region is undergoing a boom, because an economic boom in Sub-Saharan Africa or in India will affect the copper market differently, due to the differences in the access to the electricity.

7

CASE STUDY: URBANIZATION

Introduction

The economic boom in China was accompanied and preceded by an enormous migration of people from rural to urban areas. Between 1990 and 2015 the percentage of the population living in urban areas doubled. The section discusses the relation of urbanization and the GDP per capita, how it relates to the demand for copper and the possibilities for the future.

Requirement 1

As the rate of urbanization increases, the GDP per capita increases. People move to the city for a better life. Their standard of living increases, with higher wages and better services, which has a positive effect on the nation's GDP (Commodity Discovery Fund 2015). This image is confirmed by figure 7.34, which shows that a low percentage of urban population is rarely accompanied by a high GDP. An exception is Trinidad and Tobago, which has the lowest percentage of urban population with a GDP per capita of $32000, which is slightly below the OECD average. This is because of the large petroleum industry present in the Caribbean island (ECO 2011).
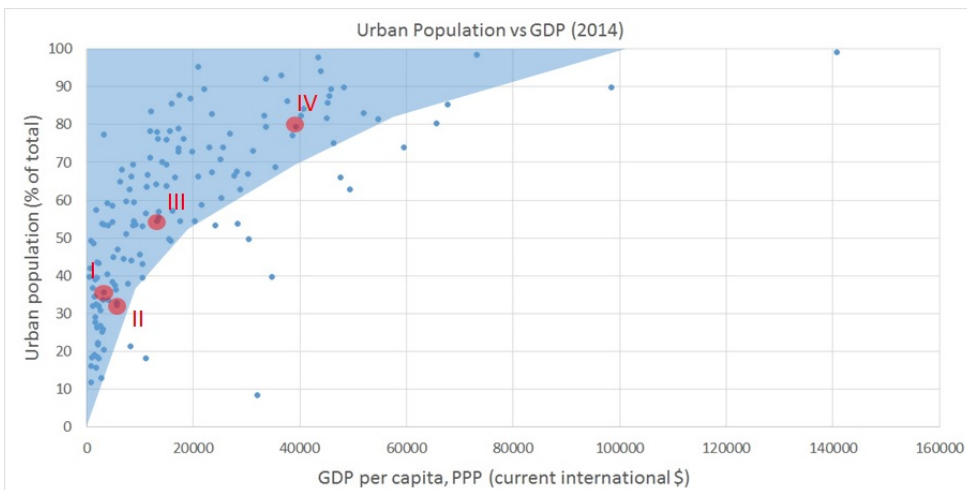
Figure 7.34: The rate of urban population of 152 countries is plotted versus the GDP per capita, PPP. The red dots represent Sub-Saharan Africa (I), India (II), China (III) and an average for the OECD members (IV). The blueish area is made by the author and covers at least 90% of the plotted countries. As the GDP increases, an upward trend in the rate of urbanization can be recognized (The World Bank 2014*g*).

Requirement 2

The massive migration of people to cities and their increase in demand for better goods and services has a direct impact on the category 'building construction'. The fast construction of urban areas requires copper wires, plumbing, heating and air conditioning. All result in an increase in demand for copper.

Potential
Compared to the OECD (80%), China has still a relatively low percentage of people living in urban areas (55%). The percentage is even lower for India and Sub-Saharan Africa (32% and 37%). The global average is 53%. For the last 40 years China and for the last 55 years the OECD members, India and the world on average have experienced an ongoing urbanization. Due to the absence of a turning point for both the under- as developed parts of the world it is likely that this trend will continue. Considering the position of urbanization in India, Sub-Saharan Africa and China, all three nations continue to urbanize, which will affect the copper industry.

Conclusion
Due to historical tendency, urbanization is a conventional driver, which has affected the market continuously over at least the last 55 years and will affect the market in the future. However, an economic boom can cause an acceleration in the migration. Because of the sizes of population of India, Sub-Saharan Africa and China, all three regions have (still) the potential to cause this acceleration. Due to the direct impact on commodities, like copper, developments in urbanization are considered to have a significant impact on the demand for copper.

7

CASE STUDY: HIGH TECHNOLOGY EXPORTS

Introduction

Products with a high research and development intensity are considered to be high-technology. These products are often used in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery (The World Bank 2014*c*). Their origin and influence are discussed as follows.

Requirement 1

Due to the efforts required for investing in extra research, instead of providing basic needs, high technology products are often assumed to be made in developed nations. This statement is confirmed in figure 7.35. However, the correlation evaporates for nations with a GDP per capita of above \$20.000. A nation with a high GDP per capita, does not necessarily have a high export value of high technology products.
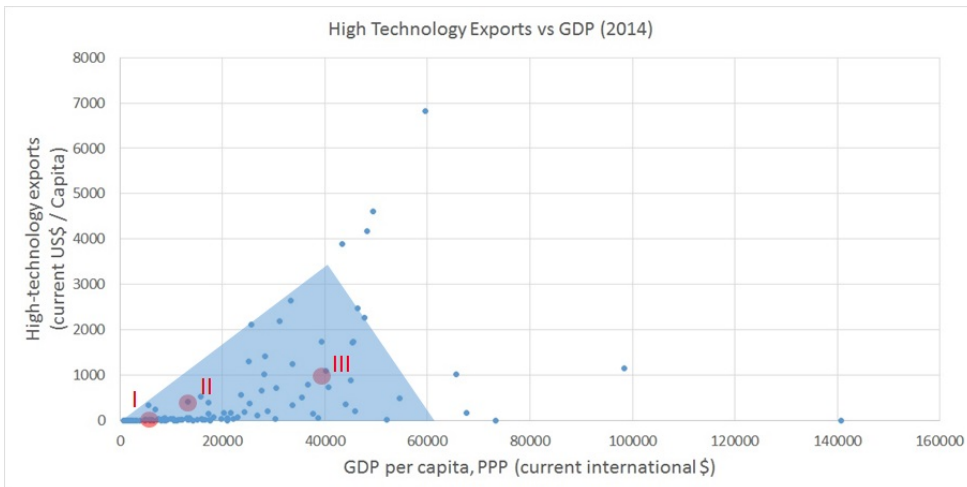
Figure 7.35: The export of high technology products per capita of 114 countries is plotted versus the GDP per capita, PPP. The red dots represent India (I), China (II) and an average for the OECD members (III). The blueish area is made by the author and covers at least 90% of the plotted countries. Although nations with a low GDP, have a negligible export of high technology products, the correlation does not exist for nations with a high GDP (The World Bank 2014*c*).

Requirement 2

As stated in 2.2.2, high technology products are part of the category 'electrical & electronic products'. Furthermore, copper, due to its conductivity characteristics, is an essential metal used in high technology products. An increase in manufacturing of those goods, will require a higher demand for copper (Copper Development Association Inc. 1999*b*). However, the actual demand for copper could be disappointing. Apart from information about the necessity of copper in high technology products, not much more is published.

To emphasize the volume of copper used even more, a focus is put on one product within the product group, namely mobile phones. Considering that 6 billion of people have phones and there are 2 billion phones made every year, the product has a relatively short lifetime of 3 years (Closing the Loop 2016). For phones, copper is the most used metal with roughly 142 grams. To conclude, this branch of industry consumes yearly 284kt of copper (Copper Matters 2016). In other words, 1,3% of the total copper consumption, is used for mobile phones.

Potential
Based on this indicator, no potential can be measured. For a nation with a high GDP per capita, it is possible to have both a high or low export value of high technology products.

Conclusion
This indicator appears to be insufficient. Although high technology products require copper, the actual volume of it is questionable. Furthermore, this indicator does not show a likely path of development, that would follow a booming economy. As the GDP per capita rises, most discussed indicators expect a growth. Unfortunate this remains uncertain for the export of high technology products.

7

7.3.4. CONCLUSION

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CASE STUDY: COPPER USE PER CAPITA VERSUS GDP

Introduction

Energy use, electricity access and urbanization are three indicators with a clear correlation with the GDP and all three do cause an increase in demand for copper. Besides these indicators, there may be more GDP correlated indicators with a (less) strong correlation with copper, but which still affect the demand. Based on the discussed cases, a causality between the GDP per capita and the use of copper can be made. How does this causality actually takes form?

Requirement 2

Of the three indicators, all have their strongest impact in the lower range of the GDP per capita. This is underlined in figure 7.36. Here can be recognized that as the GDP per capita rises, the copper consumptions rises too. After around $25.000, this effect wears out.
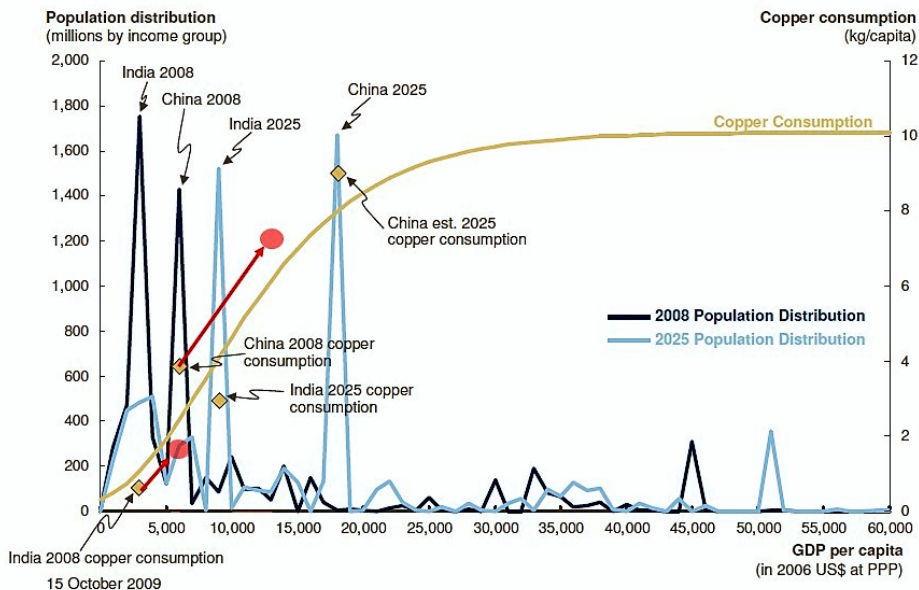
Figure 7.36: Copper use per capita. India and China are visualized. Based on this graph, Sub-Saharan Africa would be located in the left lower corner, while the OECD members are located on the asymptote above (The World Bank 2004, 2012, 2014b, Rio Tinto 2009).

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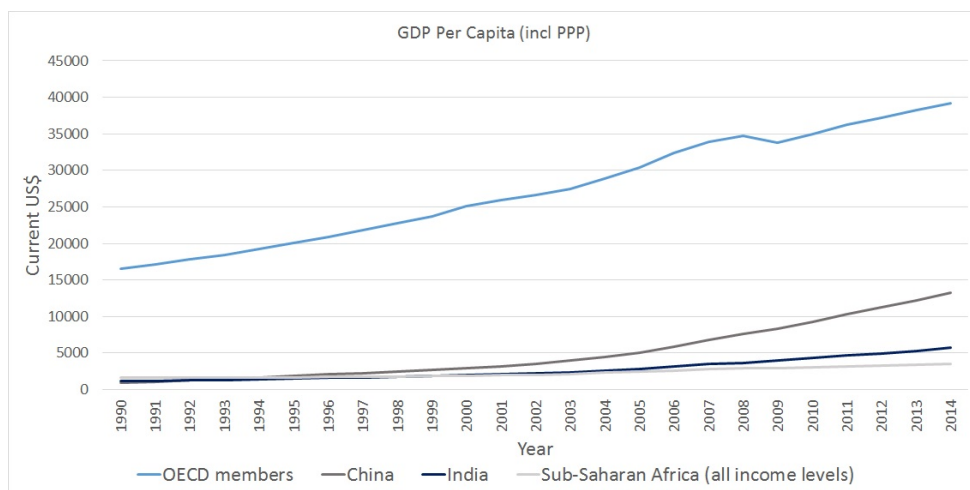
Figure 7.37: On GDP based economic developments in the OECD, China, India and Sub-Saharan Africa are shown. The pre-1990 figures, in which the PPP is included, do not exist. (The World Bank 2004, 2012, 2014*b*).

Conclusion

This GDP - Copper relation brings the current developments of the GDP per capita in India, China and Sub-Saharan Africa to a different perspective. Figure 7.37 shows how the GDP per capita has grown in all regions over the last 25 years. China, India and Sub-Saharan Africa are not even close by the level of the OECD members. However, in relation to copper, this matters less. The Chinese population is currently consuming an assumed number of 8 kilograms of copper per capita, while the average consumption for high gross domestic products is 10 kilograms of copper per capita. In other words, China has the potential to boost the yearly consumption figures of copper by only another 2Mt. India and Sub-Saharan Africa on the contrary, are only on a level of 10-20% and could therefore boost consumption by each of 8 to 9Mt of copper. Therefore, economic booms in India and Sub-Saharan Africa have the potential to affect the market significantly.

7.4. TECHNOLOGY

As explained in chapter 5, technological progress decreases costs for mining or processing and it increases copper reserves. It could therefore affect the copper price significantly. Because the role of technology covers the whole value chain, the outline of this section is the discussion of each of the chain's pillars.

Primary and secondary sources, exploration, extraction and processing will be discussed from a perspective of significance, feasibilities, opportunities and threats.

7.4.1. PRIMARY AND SECONDARY SOURCES

The first discussed pillar, is the source of copper. The metal has been mined for millennia, resulting in the depletion of a lot of the relatively easily extractable deposits. This is one reason for the low reserves left in Europe (The Wall Street Journal 2009). Exploration has become more complex (which will be discussed in section 7.4.2) and nowadays, people are increasingly exploring for alternative sources, even though there are still regions in the less developed world with high potential, such as the African Copper Belt. An alternative source can be found in the deep sea environment. This will be discussed in a case study in order to show the potential of alternative primary sources, relative to the current potential of traditional onshore deposits. Another possible alternative solution is to increase recycling. The drive for a sustainable and energy efficient society strengthens the position of this alternative, as recycling takes a large stake in policies to meet those goals. But not only this drive, but also technological innovation, could unlock more potential on the recycling market. This case study will focus on the potential of recycling copper and will discuss briefly how strategies can be adjusted to this. Last possibility is to eliminate copper as used metal, by means of substitution. Aluminium appears to be the metal with characteristics closest to copper. This will be discussed in the third case study within this section.

CASE STUDY: DEEP SEA MINING

Introduction

Over the last decade, Nautilus Minerals has become the first company to commercially explore the deep sea (Nautilus Minerals 2016*b*). This case study will briefly discuss their findings and will put the opportunities and problems, yet to be overcome, in a bullet pointed list.

Objective

What are the opportunities for the deep sea copper deposits and what problems still need to be overcome?

Data

The following opportunities of deep sea copper deposits are identified.

- High grades of copper and gold (~ 7-8% Cu and ~ 3-6 g/t Gold) could make the project very profitable (Nautilus Minerals 2016*a*).
- Nautilus actively started their project in 2009 and started testing its equipment in Oman in 2016. The goal of Nautilus is to start operations in 2018. Their activities and endurance proves they are a pioneer in mining in the deep sea environment (Nautilus Minerals 2016*b,c*).

On the other hand, some problems are also recognized. Those problems however, do not illustrate the unfeasibility of deep sea mining, but show how the deep sea is still in an early development phase.

- The current resource estimates are low. Ores, containing in total 75 kt of copper, are classified as indicated[1] ores, containing 140 kt, are classified as inferred resources (Nautilus Minerals 2016*a*). Compared to the annual production of 18,000 kt (USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013), or the USGS reserves estimation of 720 Mt, these amounts are negligible in the global market (USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013).
- Nautilus has identified many potential areas, where the specific type of copper deposits can be found. Many of those areas are either in international waters, or not fully explored yet (Nautilus Minerals 2016*b*, USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013).

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[1]The terminology of inferred, indicated and measured resources are used to classify the certainty of a deposits. An upgrade to probable or proven reserves, tells the certainty of an economic feasibility of the deposit (JORC 2012).

Conclusion

Leading mining company Rio Tinto expects a continuing increase in demand of 1 Mt per year (Rio Tinto 2016*e*). The total size of currently explored deposits by Nautilus does not even come close. This is illustrative for the main issue about deep sea mining, that it is still in an early development phase. In spite of this issue, Nautilus has proven that their research and development endures and that they are testing their equipment. Deep sea mining could become an important factor within the mining industry, if Nautilus Minerals would be able to start to mine successfully in 2018. Therefore, deep sea mining is an issue, the effect on the market could be significant on the very long term.

7

CASE STUDY: POTENTIAL OF RECYCLING

Introduction

To determine the potential of copper recycling, a study of the USGS from 2010 was used. It discusses; the recycling in the U.S. in 2004, which old scrap is used and what the recovery rates are alike (USGS 2010*a*). This case study will explain the used methodology briefly and projects it a time series and discusses the present. To start with, some general terms are explained:

- **Old and New Scrap**: New scrap consists of scrap which is produced during the manufacturing of products, but ended up in failed products or as residue. While old scrap is the copper retrieved from products that reached their end-of-life (USGS 2010*a*).
- **Recycling Efficiency**: The part of all available scrap, ready to be recovered and reused, which is actually recovered and reused (USGS 2010*a*).

Objective

To what extent can the recycling of copper affect the copper market?

Data

The time series for the copper price and the recycling of copper are shown in figure 7.38. Noteworthy is the cyclical behaviour of peaks and troughs in the copper market and the continuous growth of the secondary supply. The latter appears to be only slightly affected by the copper market. However, due to the low copper price, a decline in the secondary supply started in the late nineties and maximizied in the early 2000's. Eventually, the economic boom in China (section 7.3) changed it back and affected the recycling market by causing a rapid increase of secondary supply to the copper market.
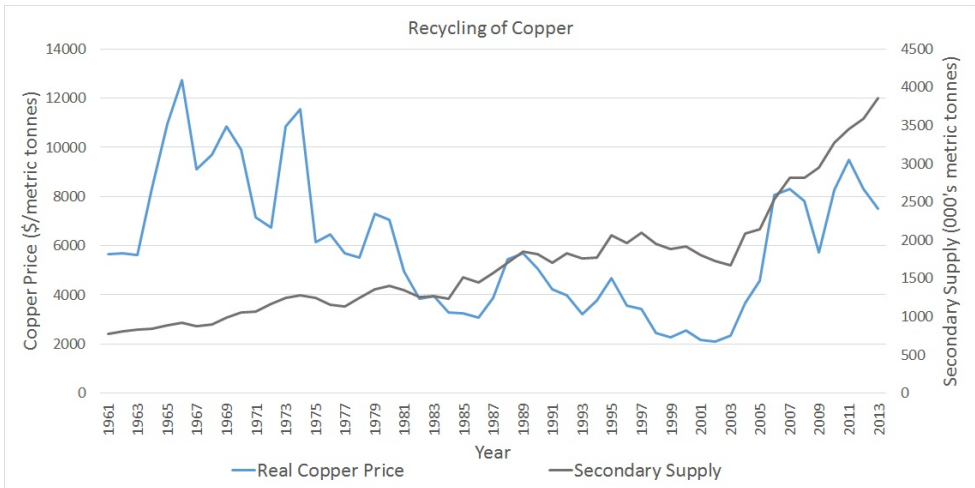
Figure 7.38: The copper price and the recycling of copper. (USGS Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013).

In general, it does seem that the recycling market is less influenced by the copper market. Reasons for this could be the production costs, which might be lower compared to mining. Furthermore, it could be that the recycling market is more affected by other factors. This is shown by USGS (2010*a*), which states that the recycling market is more affected by historical consumption. Deeper research on this will indicate how the recycling market is likely to progress in the future and what opportunities lay ahead.

Potential

The study used in this thesis assumes that the lifetime of products is Gaussian distributed[1] which is in conformance to common practice. The amount of available old scrap can be approximated by using this distribution by estimating which and how many products reach their end-of-life. Finally, by implementing the historical copper consumptions, an amount of old scrap, available for recovery and reuse, is approximated. The average lifetime and spread is given in table 7.1(USGS 2010*a*).

Table 7.1: Figures, which are used in calculating an approximation of old scrap, available for recovery and reuse(USGS 2010*a*).

Product Group	Share[2] (%)	Average Lifetime Products	Spread[3]
Building and Construction	30	40	35
Electrical and Electronic Products	39	18	16
Transportation Equipment	12	18	16
Consumer and General Products	10	10	10
Industrial Machinery and Equipment	9	18	16

[2]Global share of end uses in the specific product group in 2014(GFMS 2013, 2014, 2015, 2016). [3]The spread is different from the standard deviation and is about two times the average lifetime within a product group (USGS 2010*a*).

The total available old scrap is calculated for 1980 and 2013. For every year, in advance of 1980 or 2013, the amount of scrap becoming available within each group is calculated. This results in figure 7.39. The area below each of the curves represents the total amount of old scrap, which came available in 1980 and 2013. Those numbers are respectively 5,2 Mt and 11,4 Mt. The recycling efficiency can now be calculated and is shown in table 7.2.

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[1]The used Gaussian distribution is according the formula: $y = \frac{1,6}{b} \times e^{-8\left(\frac{(y-a)}{b}\right)^2}$. Wherein y stands for the year, in which the contribution of old scrap is calculated. Furthermore, is a the average life of the material and b is the spread (USGS 2010*a*).
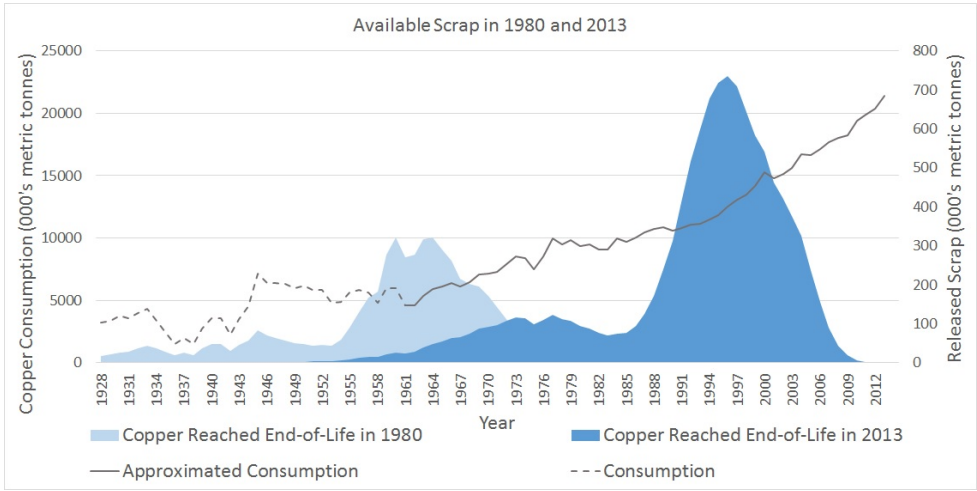
Figure 7.39: The area below each of the curves represents the total amount of old scrap, which became available in 1980 and 2013. Those numbers are respectively 5,2 Mt and 11,4 Mt (USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013).

Table 7.2: The available old scrap, the actual amount of secondary copper processed and the recycling efficiency (USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013).

Year	Available Scrap	Recycled Copper	Recycling Efficiency
1980	5,2 Mt	1,4 Mt	27 %
2013	11,4 Mt	3,9 Mt	33 %

Those values show that only one third of the available old scrap is actually recovered and reused. The unrecovered materials have ended up on landfills or have dissipated, due to their use in, for example paints and fertilizers. In some of these scenarios, the copper could still be extracted in the future, when the price is high enough (USGS 2010*a*).

This method, used to calculate the recycling efficiency, could also be put into a sensitivity analysis, which will create a time series of how the recycling efficiency has developed over time. Figure 7.40 shows the resulting time series.
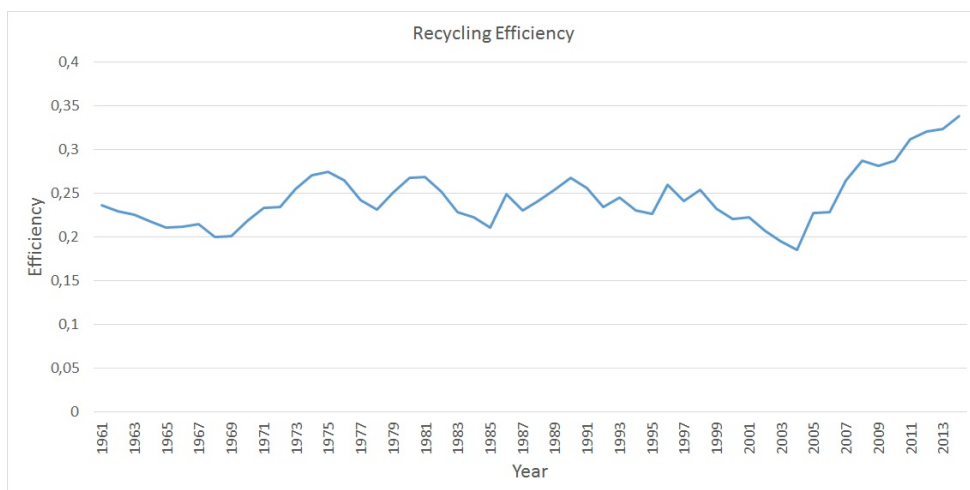
Figure 7.40: The method applied used in a sensitivity analysis, to create a time series of how the recycling efficiency has developed over time.

As can be seen, the recycling efficiency has always been low, with an average of around 25%. Since 2004, the efficiency has risen to almost 35%. All these numbers are quite low. Especially taking in mind, that the phrase "at least 80% of all copper ever mined is still in use or available for use" is often published (Copper Alliance 2016*a*). A structural loss of 65% of the old scrap is alarming, especially while the world is willing to establish a more sustainable and energy efficient society. Some explanations for this are given below, but all of them would need more research.

- The average lifetime and spread are not correctly determined. A higher lifetime and smaller spread would decrease the available old scrap and would improve the resource efficiency.
- The statement is based on skewed data. Most copper is relatively recently mined and consumed, while the old scrap originates from times with lower consumption. This method can be used to calculate how much copper is trapped in products which are still used. This results in a percentage of 68% of the amount of copper which is mined in the period 1960-2014. This means that the statement is misleading and the value of 80% will eventually be outdated.
- A big part of the unrecovered copper could still be considered available. This, because copper does not lose its performance over time (Copper Alliance 2016*a*).

Strategies

The current recycling efficiency is very low and offers a lot of opportunities for companies. The recent rise could be accounted by a very innovative recycling market, wherein a lot of new opportunities have been discovered. Many of those examples are found in urban mining, which unlocks many of those unrecovered sources. Policy makers could

consider a stronger focus on copper. The statement that 80% of the copper is still in use is misleading and blocks the drive for more sustainability.

Conclusions

The recycling market has mainly ignored the price cycles in the copper market. An explanation for this could be found in possibly lower production costs, or the dependency on historical copper consumption. This could be a factor which constrains growth more than the actual copper price. The methodology, used in this case study, calculates the amount of available old scrap. Comparing it with the actual secondary supply results in very low values for the recycling efficiency. This offers both opportunities for businesses, as worries for policy makers who need to meet goals on sustainability and energy efficiency. However, there are a few possible reasons identified, that could affect these results significantly, but on which more research is desired.

7

CASE STUDY: SUBSTITUTION COPPER BY ALUMINIUM

Introduction

A threat for the market of a specific material is the possibility to replace it by another material. If the price rises too high, or if the characteristics of the replacing material are more favourable, substitution occurs. For copper this is aluminium.

Objective

What is the likelihood of substitution of copper by aluminium?

Data

A set of important characteristics can be identified. Based on the necessity of certain factors, the preferred metal can be chosen. Those characteristics are as follows (Siemens 2014):

- **Price[1]:** One of the main reasons for a shift from the use of copper to aluminium is the price of the metal. In general the price for copper is 3 times as high, which makes aluminium more favourable (Siemens 2014).
- **Volume:** Apart from alloys, copper has a much lower resistivity than aluminium. In order to use aluminium, without increasing the resistivity, the volume needs to be increased by 68% (Siemens 2014).
- **Heat:** Copper has a much higher thermal conductivity than aluminium and is therefore more suitable to dissipate heat. This makes copper a commonly used metal in the heat exchangers of heavy duty vehicles or new generations of computers (Finnradiator 2016, Copper Development Association Inc. 1999a). Furthermore, aluminium has a relative high thermal expansion. Especially for high temperature differences or large distances, this could become a problem (DNV GL 2016).
- **Weight:** For lightweight products, which are not constrained by a maximum size, aluminium would be more suitable. The density of aluminium is 1/3 of the density of copper (Siemens 2014).
- **Strength:** Comparing the pure metals, copper has more strength. But electrical grade aluminium alloys and copper relate as about 1:1. The consequence for aluminium is, that the alloys have a higher resistivity, so the volume needs to increased to become a competitive alternative. Instead of 68%, this goes up to 85% (Siemens 2014).
- **Surface Condition[1]:** Aluminium is much more vulnerable to quick surface oxidation. However, the issues related to the metal surfaces can be overcome (Siemens 2014).

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[1]Another often used metal as electrical conductor is gold. The main reason is that gold does not oxidise and is highly conductive, which is suitable for very thin conducting contact points. (Geology.com 2016). However, the electrical conductivity is not as high as copper and the gold is considered a very expensive metal. Due to these reasons, the use of gold is limited to a very few uses.

Besides these basic characteristics, there are a lot of product dependent requirements, such as the ease to connect all lines within a network to each other. Another example is the use of specific alloys, e.g. a complex alloy of copper with indium and selenium is used in solar cells and copper-aluminium alloys with iron, nickel and magnesium additions are improving substitutions of carbon steel. All this makes the substitution of copper a very complex topic.

Conclusion
As stated, the determination of the likelihood of substitution is very product-dependent, because every product has different specifications. Nevertheless, a few themes can be identified which are becoming more important. There is certain need for more efficient and smaller products. This requires a high electrical- and thermal conductivity. In both characteristics, copper surpasses aluminium (Copper Development Association Inc. 1999*a*). On the other hand, aluminium also has its benefits. If the desire for smaller products weakens or the copper prices rises too high, the use of aluminium would increase. Monitoring the people's demand can help to determine which characteristics fit best. This is a way to tell how likely substitution is.

CONCLUSIONS PRIMARY AND SECONDARY SOURCES

Alternative sources of copper, like the deep sea or old scrap, were discussed using case studies. Mining deep sea copper deposits appears to be feasible, but the amount of ore in these deposits proves that deep sea mining is still in an early development stage in which the exploration is still inadequate. Recycling however, is currently experiencing a boost in technology. But even then, recycling efficiency remains low and a lot of old scrap has disappeared.

Last is the need for products with high electrical- and thermal conductivity. Copper beats aluminium in both characteristics. This indicates that the likelihood of substituting copper by aluminium is low.

The main outcome is that there is still an enormous unused potential for alternative sources. But the large amount of global copper reserves weakens the incentive to search for alternatives. Furthermore, the idea of a large amount of global copper reserves indicates that this subject is of less influence on the copper market. But the exploring, extracting and processing of those deposits could be of influence.

7.4.2. EXPLORATION

This section will not discuss exploration and its influence on the copper market, because this has already been discussed in section 7.1.1.2.

What will be briefly outlined, are the implications for exploration and the consequences of deposits, which require a more complex extraction. To start, exploration technology has improved over the last decades. With the use of imaging tools, exploration teams are much more capable to discover and map geological deposits (The Wall Street Journal 2009). This improving technology has discovered new deposits in areas, that slowly became more and more exhausted. The new deposits, most often with relatively high ore grades (2.2.1), are more often found in non-OECD areas (Rio Tinto 2016*d*), which are not fully explored yet and traditional exploration is still applicable to these regions. Many new deposits are found in Africa and between 2015 and 2018, nine copper mines will become operational (Deloitte 2015).

As will be discussed in section 7.5, some regions in Africa are relatively unstable. New deposits in the OECD region however, do require a more complex extraction operation, due to lower ore grades (2.2.1) or an increasing depth of the deposit. To avoid mining in unstable regions, companies need to adapt to these changing characteristics. Options are to expand their operations to deeper levels and/or process ores with lower grades of copper. Those challenges will be discussed in the next section and the corresponding case studies.

7.4.3. EXTRACTION AND PROCESSING

The next pillar discussed is the extraction of copper. The marginal costs, as an indicator for the current state of extraction and processing, have already been discussed in chapter 6 and section 7.2.2.1. In section 7.2.2.1 it was discussed in the context of a relation with the oil price, as the mining sector consumes a lot of (petroleum) energy. The conclusion was that the situation is much more complex and that an improvement in extraction or processing technology is more significant. An example is the improvement of processing technology that shaped the time series for at least the first 40 years. During this time, low productivities have disturbed the time series and the recent rise of the copper price has potentially evaporated the incentive to reduce marginal costs.

This section will discuss how extraction and processing affect the marginal costs and with that the copper price. Threats and opportunities will be identified in both cases.

7

Introduction

Increasing demand is a strengthening trend and every year's increase, is mainly compensated by an equal increase of supply. Figure 7.41 shows how the two time series increase at the same rate.
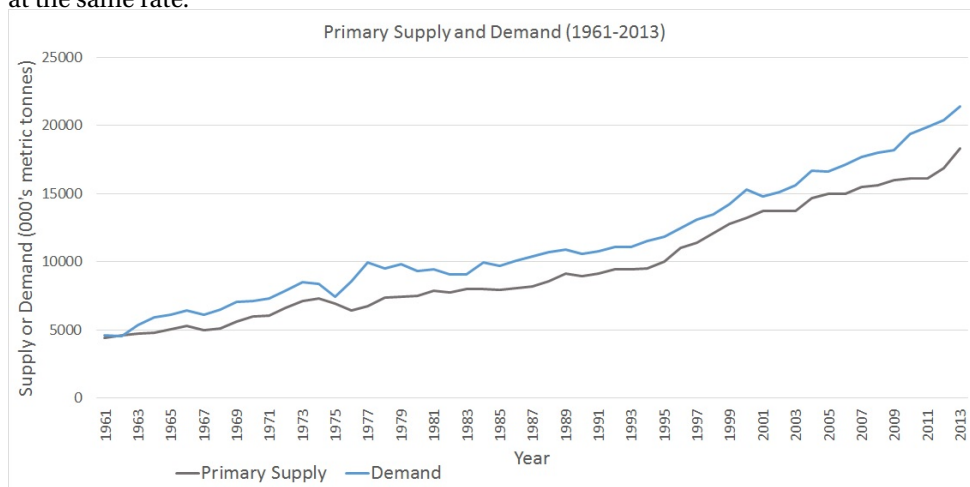
Figure 7.41: Yearly figures of primary supply and demand for copper. The gap between the primary supply is filled with secondary supply and changes in inventories (USGS Commodity Summaries 1996-2016, USGS Minerals Yearbooks 1960-2013).

There are not enough major discoveries of deposits to keep up the demand, by opening new mines. Another way is to keep up this increase in production, to expand current mines. Often, mines can only expand in one direction: vertically down (The Wall Street Journal 2009). The deepening of mines brings a set of new challenges for the copper market and could affect the marginal costs significantly. This will be discussed in this case study.

Objective

In what way, do deeper mines affect the copper market and how significant are those issues?

Data

At least three challenges are brought along with the deepening of mines:

1. A decrease in ore grades and an increase in the length of cycle times[1] are big contributing factors to an increase in marginal costs (The Wall Street Journal 2009).
2. Expanding the pit vertically down, while retaining the operation on the surface, is infeasible.

3. Deepening a mine increases the risks of wall instability. A recent example of such wall instability is the landslide in the Bingham Canyon Mine in the USA (section 7.1.1.3).

The main applied solution to this set of challenges is to transit the operation from the surface to the underground. As discussed in section 7.1.1.3 and figure 7.3, developments on one mine specifically do not affect the market significantly. However, The Wall Street Journal (2009) has recognized the transition to underground operations as a tendency and identified at least five major mines[2], that have set the transition in motion. However, this solutions does not solve all three challenges. Feasibility and safety have been given the priority, but due to a lower production volume and high capital cost for an underground infrastructure, the marginal costs continue to rise. Because the development is identified as a large scale development, this will certainly affect the marginal costs and therefore, the copper market as well.

The main issue for large open pit mines, causing the rise in marginal costs, is the length of the cycle time and the additional increasing costs of removing waste (Mining.com 2012). In order to remain a surface operation more profitable than an underground operation, such as a block caving operation, those costs need to be bypassed. Innovation on these areas are required.

Conclusion
A tendency is recognized in which mines are increasing in depth and transitioning their operations to underground. This tendency is accompanied by challenges, such as the increased length of cycle times. This causes an increase in additional costs in the discharge of waste. This factor does contribute significantly the increase of marginal costs. If this challenge can't be solved, another opportunity to decrease the costs lays ahead in the processing technology. Furthermore, in order to maintain the mining operations in global safer regions, companies need to adapt their processing to generally lower grade ores (figures 2.3, 2.4 and 2.6). Next case study will focus on how processing technology has affected the copper market.

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[1]A cycle is the loading and discharge of ore and waste from the bottom of the pit to the surface.
[2]Bingham Canyon Mine (U.S.), Resolution Mine (U.S.), Ernest Henry Mine (Australia), Grasberg (Indonesia) and Chuquicamata (Chile).

CASE STUDY: FLOTATION TECHNOLOGY

Introduction

A major technological development in copper extraction, which occurred in the 20th century, was the implementation of 'froth flotation'. This is a process wherein hydrophobic and hydrophilic minerals are separated from each other. The history of the development of the technology shows how the impact was, and how important it was. This is shown in the timeline below (Wills & Atkinson 1991, USGS 2009, MinEx Consulting 2010):

1906	Technique is patented
1907	Current copper production is from underground vein deposits with an average grade of 2,5%
1930's	First introduction of mill using only flotation
post war	Increase in demand, due to large growth industrialisation
1960's	Increase in discovery of large, low grade, complex and sulphide ore deposits
1970's	Real costs of computing decrease rapidly
1970's	Industrial boom ended and commodity prices fell
1971	Technology is extended to non-sulphide ores; Mines reopen
1975	Amount of U.S. ore, treated by flotation, doubled over the last decade
1980	15% of global copper production origins from flotation
1980's	Flotation columns represent the next level in flotation technology (pneumatic versus mechanical techniques)
1980's	Rapid increase in scientific research towards flotation technology
1980's	The flotation technology is further improved
2009	75% of mined copper origins from Porphyry deposits
2010	Average grade of the mined ore decreased to 1,07%

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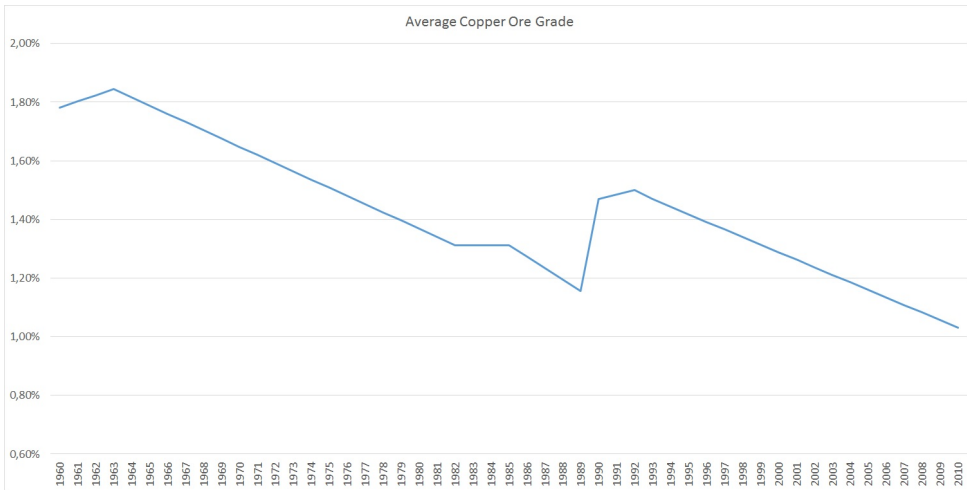
Figure 7.42: The average mined copper ore grade over the years (MinEx Consulting 2010).

Nowadays 75% of the copper deposits are Porphyry type, wherein mainly flotation technology is used. It is likely to stay like this, due to the roughly 75% of the reserves, which are also Porphyry type deposits (2.2.1). Furthermore, it remained economically feasible to mine ore, even when the grade dropped to an average of 1,07%, as is illustrated in figure 7.42. In chapter 5 it was suggested that this development was the cause for the long term downward trend of the copper price in the 80's and 90's. If this is true, then the actual marginal costs had to go down as well.

Objective
Was the development of flotation fast enough that it could have caught up and overtake the speed of how extraction becomes more complex in terms of depth and ore grades?

Data
The acquiring of the data on the marginal costs is discussed in section 6.3.3. It has to be noted that there is an error in this data. Several sources were used and gaps are estimated by extrapolation and/or reconstruction. The restuls are shown in figure 7.43.
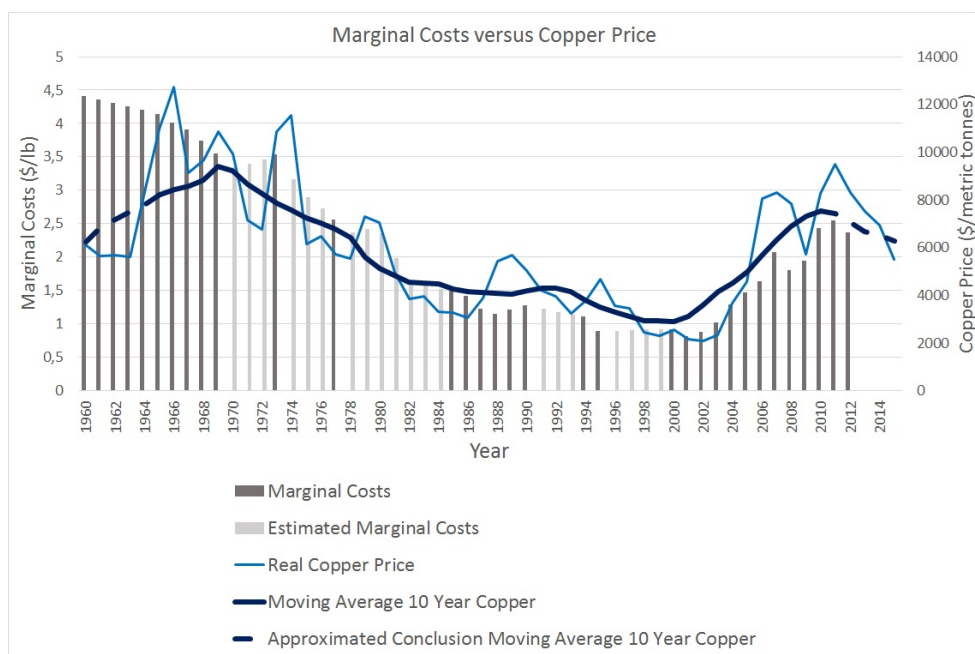
Figure 7.43: The marginal costs of copper production (Mikesell 1979, USGS Minerals Yearsbooks 1960-2013, Wood Mackenzie, Bloomberg and AllianceBernstein 2015).

Interpretation

For over 40 years the marginal costs show a downward trend. Some exceptions occurred in the early and late 70's. Those two periods are most likely linked to the two oil crises and are discussed in more detailed in section 7.2.2.1. From 2001 and on, the marginal costs started to increase (rapidly). This can possibly be explained by the following reasons:

- The rate of improving processing technology may not keep up with the speed of how extraction becomes more complex in terms of depth and ore grades.

- Due to high copper prices, the incentive or practicability to minimize the production costs weakens. This causes an increase in production costs (thus the marginal costs) (Tilton 2014).

Conclusion

Marginal costs and the ore grade are two factors that have an inverse relation. Both, show for over 40 years, the same downward trend. The developments and improvements in flotation technology, which occurred in the same time span, had an immense impact on the processing techniques used in the copper mining industry and this development seems the most plausible cause for this.

It is likely that the effect of this development is worked-out or can't keep up with the speed of the market. Another possibility are the high copper prices, which weaken the

incentive or the practicability to minimize production cost (Tilton 2014). To conclude, the impact of technology on the market is immense. However, it is most likely that the copper market is in a high need of a new form of development or a next generation of the flotation technology.

OTHER CHALLENGES IN EXTRACTION AND PROCESSING

Some other operational challenges have been identified and are briefly listed.

- Mining operations need to increase their mitigation on supply risks like energy or water (CODELCO 2015).
- Successful exploration continues in under developed regions. Those regions bring challenges such as high risk and high capital costs in the form of new infrastructure (Deloitte 2015)

CONCLUSIONS EXTRACTION AND PROCESSING

The current mining sector is facing a lot of challenges and there is no perfect solution. The extraction industry will have to mine deeper in OECD regions, due to that new discoveries are located deeper than historic discoveries (Rio Tinto 2016*d*). This pushes the mining companies to start mining in relatively unstable regions or into the expansion of already operating mines, facing challenges in increasing depths and decreasing ore grades. The consequences are increasing costs in the removal of waste in surface mines or building an infrastructure in underground operations. Both are a big contributor to marginal costs.

Furthermore, decreasing ore grades are the challenge for the processing industry. The industry experienced for decades a continuous improving technology. However, ore grades continue to decrease and marginal costs have increased. This indicates that the improvement in technology, does not keep up with the speed of changes in the market. A new generation of flotation or an alternative technique could change this.

In order to continue operations, which are either safe and cheap, new innovations are required. By monitoring the developments and implementations in the mine logistics and the processing technique, future scenarios for trends can be defined.

7

7.4.4. CONCLUSION

Companies continued to discover new deposits on regular basis. Instead of putting pressure on the copper industry, it opposes innovation towards alternative sources like old scrap. The recent economic boom in China had a very positive influence on the recycling industry, but the recycling efficiency remains low and large amounts of old scrap are lost. This is unwanted, because it blocks the drive for a more sustainable society.

The amount of copper reserves continues to grow, because of successful exploration of copper deposits. However, most of the new deposits are either located in more unstable regions, or require a more complex extraction, in terms of the mining depth and ore grade.

The increasing demand for copper needs to be satisfied. This drives copper producers to either start producing in more unstable regions, or to expand to deeper levels. Both situations cause an increase in marginal costs and due to the large scale of this development, it is likely it does have a significant effect on the copper market.

One of the issues, additional to more complex deposits, is the decrease in ore grade. It lays the challenge at the processing industry, which experienced for decades a continuous improving technology. However, this trend has weakened and the technology needs a new generation or an alternative.

To conclude, the foundation for an incentive for innovation in the mining industry has a solid base, but is not yet fulfilled. As long that this is not the problem, it will cause structural relative high marginal costs and therefore, affects the copper market as well. Monitoring the development and implementation of technology on discussed issues, could help to foresee potential scenarios in the copper industry.

7

7.5. ACCESSIBILITY/AVAILABILITY

Occasionally over the past 50 years, situations have occurred which have emphasized how important national issues are for the copper market. The sudden destabilization of a country or the downturn of a nation's investors climate can have significant negative effects on the copper industry. The same holds for the opposite, in which positive developments cause positive effects. This section will discuss precedents and identify potential threats and opportunities in the corresponding indicators. Starting with the fragility of state.

7.5.1. FRAGILITY

CASE STUDY: FRAGILITY INDEX

Introduction

As stated in chapter 5, nationalization in Chile and the following Chilean Coup d'état had a high impact on the copper market. The theme of nationalizations is discussed in more detail in section 7.5.2.2. This section will discuss the impact of a nation, such as Chile, which destabilizes. But to understand why it had such an impact, and how these kind of developments affect the copper market nowadays, it is necessary to know what Chile's share of production was in the early 70's. Figure 7.44 shows the share of production for the earlier discussed nations in 1972.
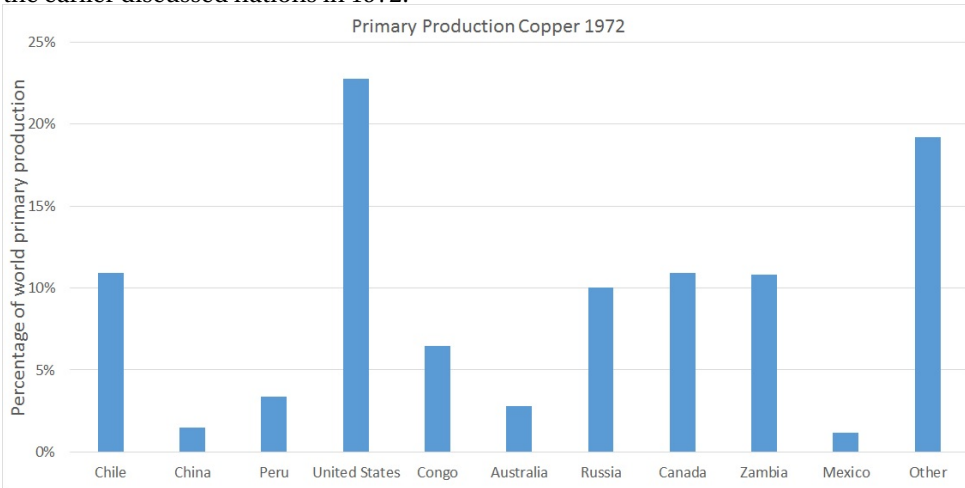
Figure 7.44: The primary production of copper in 1972. *Figures of Russia are originally reported as figures of the Soviet Union.

Chile accounted for only 11% of world wide production in 1972. The consequence of the unrest was a rapid increase of the copper price. These events could nowadays cause an even more extreme impact, due to the increase of Chile's share of production to 30%. Based on an extrapolation of this causality, one can say that unwanted developments of the same kind in China or Peru, would have similar consequences on the copper market. This due their share in world production of respectively 9% and 7% (USGS

Commodity Summaries 1996-2016, USGS Minerals Yearsbooks 1960-2013). From there on, the impact would decrease, for every step downward in the ranking. It is unknown if this decrease is linear, exponential or something else.

Following the chain of Chilean events in how they occurred in the late 60's and early 70's, two developments, that affected the copper market, can be recognized:

- Nationalization of foreign mining companies. This development will be discussed in section 7.5.2.2.

- The sudden destabilization of the nation, due to the coup of General Augusto Pinochet (CODELCO 2016, Léniz 2016).

As the Chilean example shows, destabilization has the potential to cause supply disruptions on the market. On the other hand, it can be said that a sudden stabilization of a nation could cause an oversupply. The goal of this case study is to show how fragile the main copper producing countries are. Based on this indicator, threats and opportunities can be identified.

Data
The organization Funds for Peace publishes every year an index of the fragility of all member states of the United Nations. The quantification of the index is based on thousands of articles and reports and are processed by a self made 'Conflict Assessment System Tool'. This 'level of fragility' focusses on several smaller indicators like national tensions between groups, migration of intellectuals, uneven economic development, human rights violation or factionalized elites and would give an indication how easily a nation can destabilize. The results for the main copper producing countries are shown in table 7.3 (Fund for Peace 2015).

Table 7.3: The results of the fragility index. In 2005 only nations with a warning or alert were reported in more detail (Fund for Peace 2015).

| | Fragile State Index | |
	2015	2005
Australia	Sustainable	-
Canada	Sustainable	-
Chile	Stable	-
China	Warning	Warning
Mexico	Warning	Warning
Peru	Warning	High Warning
Russia	High Warning	High Warning
United States	More Stable	-
Congo (DRC)	High Alert	Very High Alert
Zambia	High Warning	-

Interpretation

As table 7.3 shows, four of the ten main copper producing countries are weak states and one is a failed state, according to the organization Fund for Peace. Only Zambia has destabilized over the last decade and the situation in the other four nations either improved or remained the same. To emphasize the fragility of the Copperbelt nations Zambia and the Democratic Republic of Congo, data was gathered of yearly fatalities in conflicts in both regions. This is shown in figure 7.45. It is clearly visible that the Democratic Republic of Congo is overcoming a very aggressive period, while Zambia experienced an upsurge of aggression shortly after 2005. This is in line with the fragility index.
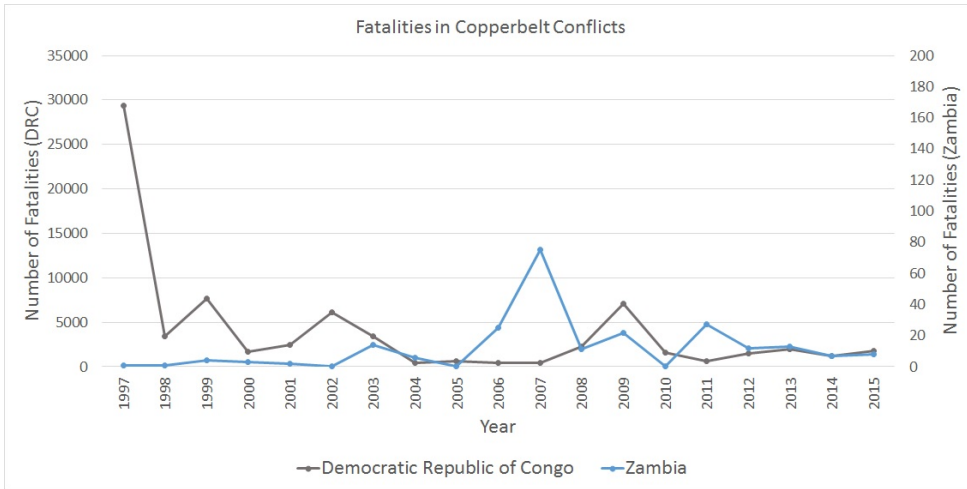
Figure 7.45: The number of fatalities in conflicts in Zambia and the Democratic Republic is used as indicator for the stability within the nations. It is clearly visible that the Democratic Republic of Congo is overcoming a very aggressive period, while Zambia experienced an upsurge of aggression shortly after 2005 (Armed Conflict Location & Event Data Project 2016).

Disregarding the more stable states, a few 'what if?'-scenarios can be identified:

- If a weak or stable state, like Chile, destabilizes, it could rapidly cause a large supply gap on the global copper market.

- If a weak or failed state, like Congo, stabilizes, it could cause an increase in mining activity and potentially an oversupply on the market. Those effects would be notable on the long term.

The likelihood that those scenarios are going to happen, depends on political, social and economical developments. In order to anticipate on those developments, a continuous monitoring would be required.

Conclusion

Every year the organization Funds for Peace publishes an index of the fragility of all member states of the United Nations. This index can be used as an indicator for the stability of a state and also for the likelihood that a nations (de)stabilizes. Risks and opportunities can be identified in weak nations which would respectively destabilize or stabilize. Unfortunately more than half of the nations in the top 10 producing countries are not considered to be stable states.

Consequences of (de)stabilizing would be an increase (or decrease) of copper supply towards the global markets, which would relax (or tighten) the markets. By monitoring those weak states, one can anticipate for ongoing developments.

7

7.5.2. Discount Rate

The climate of investment in a nation is important and depends on several risks. The climate of investment is best represented by the discount rate, which can be interpreted as the risk of doing an investment. If this climate of investment is unfavourable, investors would avoid the nation and nothing would be mined. So the lower the rate, the higher the chance for getting a return on the investment (Investopedia 2016*a*). The crucial moment in time is, when this climate of investment changes (rapidly) in a nation. A possibility is to monitor the indicators, which are depending on national issues and make up a significant part of the eventual discount rate. To do this, the discount rate is first broken down in a few components which are, or aren't, depending on national issues (Park & Matunhire 2011):

- **Risk free rate of return:** When the investment is absolutely safe, the discount rate would be the same as the interest rate on safe securities, such as U.S. or Australian government debts (Brealey & Allen 2011*b*). A company could always decide to invest in such securities instead of investing in a project. This risk is also called the market risk and is the foundation of the discount rate. This risk does not depend on the specific investment or on the country in which the investment is done.

- **Risk Premium:** The risk on a specific investment. This is stated by:

  - **Technical risk:** Can be divided into reserve risk, completion risk and production risk. The first does mainly depends on the deposit and how the resource is measured, while the other two are related to management, design and planning. Mining companies could control this risk for at least a major part.
  - **Economic risk:** Largely depends on the commodity market. But it includes also a foreign/exchange risk. Volatile exchange rates are unfavourable for investors.
  - **Political risk:** Consists currency convertibility risk(corruption), risk for nationalization and risk of changing environmental laws and tax policies.

Some risks have a non existent or an unclear causal relation with national issues. For example the risk free rate of return, which depends on global developments, rather than national issues. Another example is the technical risk, which can mostly be overcome by the efforts of an operating company. Another risk is the economic risk that includes possible negative developments on the market for a specific commodity and the likelihood of regional financial crises, which is discussed as indicator in section 7.2.1.

Disregarding those risks, political risk remains as a main risk that reflects how national issues can affect the accessibility and the availability of copper in that country. Corruption and nationalizations are in following case studies discussed. Next case studies show how some of those indicators can be monitored and how they occurred in history.

Introduction and Data

Transparency International sees itself as "global movement with one vision, who want a world free of corruption". Every year they publish a list of the Corruption Perception Index (CPI), which expresses corruption as it is worldwide perceived by business and country analysts (Transparency International 2015). The results are shown in figure 7.46.
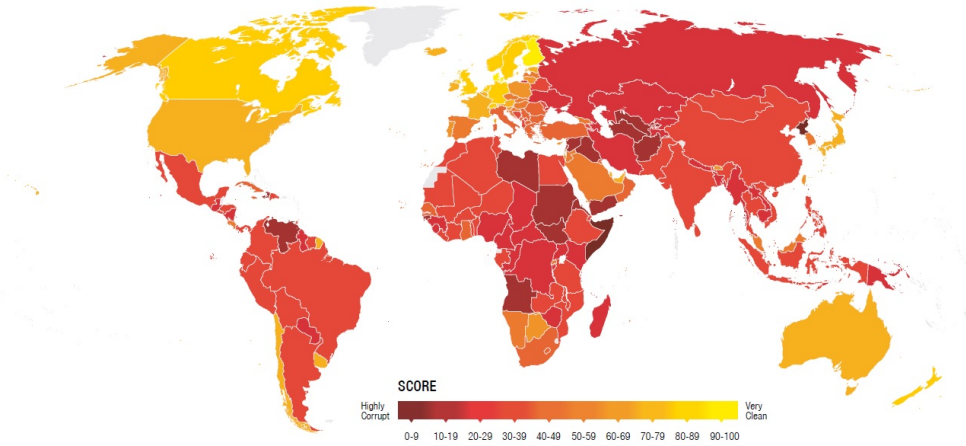
Figure 7.46: The perceived level of public sector corruption in 168 countries/territories around the world (Transparency International 2015).

As can been seen the majority of countries and territories are affected by corruption. Table 7.4 shows the corruption for the main producers of copper.

Table 7.4: The results of the Corruption Perceptions Index 2015 for ten main producers of copper, compared to the Corruption Perceptions Index of 2005. In 2015, the index was measured for 168 countries/territories and in 2005 that number was 159. (Transparency International 2015, 2005)

	2015		2005	
	CPI-Score	Nr	CPI Score	Nr
Canada	83	9	84	14
Australia	79	13	88	9
United States	76	16	76	17
Chile	70	23	73	21
Zambia	38	76	26	107
China	37	83	32	78
Peru	36	88	35	65
Mexico	35	95	35	65
Russia	29	119	24	126
Congo	22	147	21	144

Interpretation and Conclusion

According to Transparency International, six of the ten main producers have a (very) corrupt public sector. Of those six, most did not or did slightly improve. However, they did not improve with the speed of many other countries in the world. Only Zambia made a significant improvement over the last decade and this could therefore be considered to be an indicator for a possible improvement of climate of investment.

7

CASE STUDY: NATIONALIZATIONS

Introduction

In Chile, also in the Democratic Republic of Congo and in Zambia, nationalization occurred in the mining sector. A limited amount of articles are available that have analysed those events in how these took place. All three examples are discussed in this case study.

Data

In history, three large scale nationalizations are identified in the copper market. Those are discussed as follows:

Chile

Consecutive left wing governments identified problems, such as insufficient growth, structural inflation, unequal distribution of income and wealth and external dependency. The president who gained power in 1964, Eduardo Frei Montalva, had set himself the goal to acquire control of primary resources and the partial nationalization of the copper industry. Later, when Salvador Allende was elected in 1970, this nationalization was extended to a complete nationalization. In the Chilean coup d'etat in 1973, General Augusto Pinochet took power and ruled Chile for 17 years. After his rule, the state was heavily underdeveloped and 550 state owned companies were privatized in order to redevelop the state. Except for CODELCO, the state-owned copper mining company, which was never privatized (CODELCO 2016, Léniz 2016).

Zambia

Zambia became independent from the United Kingdom in 1964 and in the years afterwards they believed their interests were disregarded, compared to the foreign company's own interests. Nationalization resulted in the Zambia Consolidated Copper Mines (ZCCM) (Meller & Simpasa 2011). After a few decades, ZCCM could not maintain with the necessary investments. This resulted in the early 90's in financial instability, underdevelopment and a supply disruption. The privatization programme started in 1992 and in 2000 ZCCM was completely sold (Craig 2001).

Democratic Republic of Congo

For decades, the Union Minière du Haut-Katanga (UMHK), which was established by the Belgian King Leopold II, extracted metals and minerals in nowadays the Demorcratic Republic of Congo and financed the economic growth of Belgium. The decolonization of the nation enabled the Congolese a to take back ownership. This resulted in the nationalization of UMHK in 1967. The sovereignty and the property rights over mineral resources were retaken by the new leader Mobutu and UMHK was transformed to Gecamines.

The nationalization resulted for the first few decades in a success story. However in the early 90's, the mining companies started to make losses, due to massive corruption and

theft by Mobutu, and they were forced to make joint ventures with foreign companies
(KALENGA 2015).

Interpretation

Although the root and chain of events is not the same for all three, two highly important
similarities can be recognized.

- All three nationalizations occurred in a period of high copper prices.

- All three nationalizations were grounded on very strong feelings of inequality,
  greed, corruption and theft, causing the people to retake sovereignty and the prop-
  erty rights over mineral resources.

These findings are strengthened by a research towards nationalization-privatization cy-
cles (Chang et al. 2010), which identified the same results.

An indicator for inequality is the GINI index. This index measures the extend in how the
distribution of income deviates from a perfectly equal distribution. By comparing all
published GINI coefficients, one can consider a value below 30 as low, 30-40 as medium,
40-50 as high and the more rare occasions above 50 as very high. The GINI coefficient for
the main copper producing countries are given in table 7.5, global figures are shown in
figure 7.47 (The World Bank 2013).
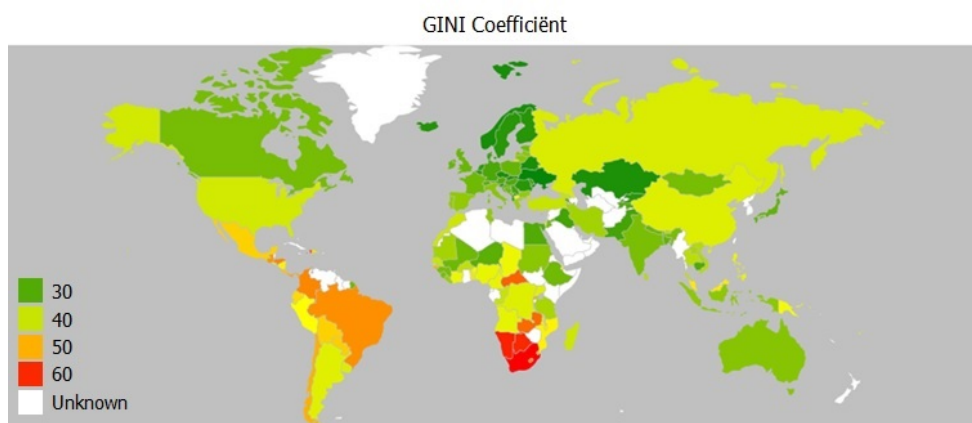
Figure 7.47: The most recent calculated GINI Coefficiënt is shown for every nation on the world. The oldest
data date 2007, the most recent numbers are retrieved in 2013 (The World Bank 2013).

Table 7.5: All recently reported GINI coefficients for the main copper producing countries. The reporting is not done consistently for every country every year (The World Bank 2013).

	GINI Index			
	2010	2011	2012	2013
Australia	34,9			
Canada	33,7			
Chile		50,8		50,5
China	42,1			
Mexico	48,1		48,1	
Peru	46,2	45,5	45,1	44,7
Russia	40,9	41	41,6	
United States	40,5			41,1
Congo			42,1	
Zambia	55,6			

Important to note is that the wealth of a nation is not taken into account. Theoretically it is possible that a very wealthy nation has a high GINI coefficient. It does not have to affect the stability, and therefore the likelihood of nationalizations, when the disadvantaged part of the society still has a high income.

Conclusion
A high copper price and a high inequality appear to be important drivers towards nationalizations. Based on the reported GINI coefficients, eight of the ten main copper producing countries have a high inequality. A very high copper price and a decreasing economical situation in one of those nations could trigger nationalization policies. Although it does not seem likely that those triggers have the same effect for all nations, due to the difference in wealth.

7

CASE STUDY: TAX POLICY

Introduction

As is shown by recent developments in Zambia, this risk can severely affect the climate of investment. To close a budget gap, the Zambian government announced in 2014 a raise in royalties from 6 to 20 percent and with no consideration of profitability (Barrick 2014).

A raise in taxes has an immense influence on the economic feasibility of the mine. As a results of the Zambian decision, Barrick Gold needed to suspend their operations in Lumwana, which produces roughly 20% of Zambian Copper and represents 0,7% globally (Barrick 2014). Besides Barrick most copper producers were losing money in Zambia (Mining.com 2015*b*).

Despite the warnings about losses and the fact that 12.000 jobs were at stake, it took until June 2015, before the government realized those warnings were valid. As result all taxes were cut and the original law was reinstated (Mining.com 2015*d*). But the damage was done. New investments, such as exploration, do not compare to their big copper producing neighbour Congo, in the perspective of Zambia's better ease of doing business (Deloitte 2015).

7

CASE STUDY: LAWS ON ENVIRONMENTAL AND HUMAN RIGHTS ISSUES
Introduction
Two examples are identified which illustrate how laws on environmental issues and/or human rights affected the copper industry significantly. One of them is more specifically related to the copper industry, the second discusses a fear of mining companies for potentially new mining laws following the Canadian election of 2015.

Pebble Mine
In the early 2000's economics and nature clashed in the southwest of Alaska in the Bristol Bay region in the form of the Pebble Project. This project is a copper-gold-molybdenum porphyry deposit, which is in an advanced exploration stage. Some experts state that the metals and the jobs, which would be created, could be worth over $300 billion combined (State of Alaska 2016, New York Times 2008).

However, the location of the deposit is unfortunate and is located beneath one of the greatest Pacific salmon rivers of the world. Worries are possible spills, which could affect this river and the accompanied fish industry (New York Times 2008).

The situation has resulted in an ongoing discussion about how to assess all different interests. The project became highlighted by the media and in 2008 the discussion even resulted in a state-wide vote for protection of the rivers. Although the vote did not pass, the project was eventually put on hold, waiting to advance the project to a next stage (State of Alaska 2016, New York Times 2008).

The debate is an example of how new laws and social debates could affect the feasibility of a project. This issue is therefore an important factor in the determination of the discount factor and an important indicator of the investors climate in a certain region.

Canada
On October 19th, 2015, the Liberal Party won elections in Canada. This meant a political shift from conservative towards liberal politics. The new prime minister, Justin Trudeau, is known for his efforts to implement bill C-300 in 2009 and 2011. Both attempts failed. But now he has the majority in the government, fears exist that he will try it again. And because three-quarters of the world's mining companies are said to be head-quartered in Canada, this fear can be considered as justified (VICE NEWS 2015).

Bill C-300 is designed to give the Canadian government a say in projects which are accused of harming the environment and/or the human rights and are financially backed by the Canadian government. Under this bill the state could receive and investigate accusations of a company's wrongdoing. Considering the amount of subsidy, $20-billion which is given by Canada, it concerns a large amount of companies. A result of an implementation of this law is that "Canada's mining companies and their financiers would now avoid projects with corrupt regimes in favour of countries that respected the rule of law" (Financial Post 2010).

The law would cause mining companies to avoid nations which are ranked negatively on the scales of corruption or fragility (section 7.5.1.1 and 7.5.2.1). This could have an immediate impact on the supply side of the copper market. Furthermore, this fear shows, that implementing new laws by nations has a large influence on the market.

7.5.3. CONCLUSION

This section has shown that the climate of investment in a country, represented by the discount rate is a good indicator for the accessibility of a nation and the availability of their copper on the market. Furthermore, it shows that smaller indicators, such as political factors and national issues, can affect the copper market. Historical events, like several nationalization or a raise in tax in Zambia, did have an immediate impact on the market. Some events, like the Chilean coup, even caused a significant impact, which was notable on the long term.

Close monitoring of the main copper producing countries in relation to the discussed indicators, can help identify early warnings. Also monitoring non-producing nations with a lot of reserves/resources is recommended. Those nations could sudden enter the market after stabilizing, which would pressure the market as well.

7

7.6. WAR/CONFLICTS

7.6.1. INTRODUCTION

As a global market, the copper market is also vulnerable for international conflicts. One of the conclusions of chapter 5 was the impact on the market that was caused by the Vietnam War. The influence of wars is discussed in the following case study. Furthermore, other potential dangers are identified in the commodity market. This is the imposing of export restrictions, the cause of which is found in confidence crises in the international community and/or resource protectionism[1]. Although they did not (yet) affect the copper market, they will be discussed, as is it considered a potential future thread (OECD 2014). Last, the correlation with the gold price is discussed, as it is considered an indicator for conflicts.

CASE STUDY: DEFENCE OUTLAYS

Introduction

One of the main reasons for the high commodity prices in the late 60's and early 70's is, according to the USGS, the war in Vietnam (Edelstein 1998). Due to the range of applications of copper in military equipment, such as electric cables in vehicles or brass in bullets, the demand increases. At the peak of the war more than 2 million soldiers were fighting on both sides, and since then, this size of war has never happened again (US Department of State, Offiee of the Historian 2013*a,b*). Taking into consideration that the copper market has grown to a size of 4 times as big as those days, it raises the question how easily the copper market can be influenced again by a war.

Objective

Do wars and war policies continue to be good indicators or drivers for the copper market? If so, then two requirements need to be satisfied.

- **Requirement 1**: There is a form of correlation between the wars and the copper market.
- **Requirement 2**: A causality can be derived between developments in the U.S. defence and the copper market.

Data

An important indicator for wars and war policies in the United States appear to be the outlays in national defence as can be seen in figure 7.48 (Department of the Air Force 2005). The data is corrected for inflation.

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[1] Resource Nationalism is the desire for a nation to gain more economic benefits and greater control over their resources and can be practised in several ways (Southern African Institute of Mining and Metallurgy 2012).
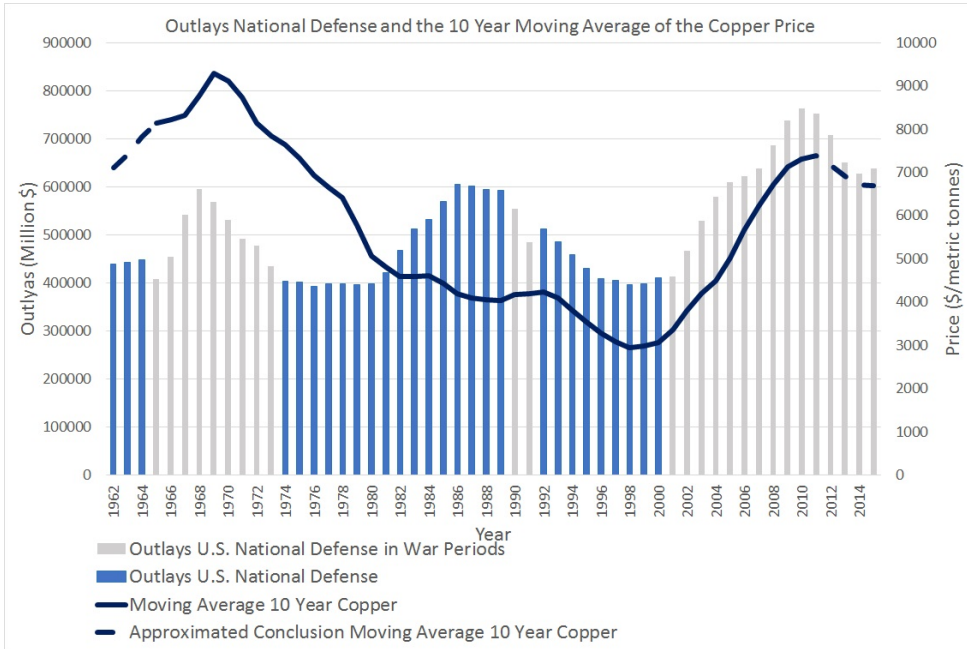
Figure 7.48: The national defence outlays of the U.S.. Years with major U.S. involvement in wars are highlighted in grey.

The grey bars represent the periods in which the U.S. was involved in a major war (total amount of both sides' troops over 1 million). Respectively the Vietnam War, the first Gulf War and the Afghan and Iraq wars combined. The high outlays during the 80's are the "Reagan Buildup", whereby President Reagan raised spending during the Cold War (US History 2016). As can be seen, this period does not show similar trends as the copper market, in contrast to the rest of the time series. Furthermore, NATO (excluding U.S.) shows more consistent outlays, Soviet figures are not available and finally SIPRI shows an increase in military spending in both Russia and China in the 2000's (The World Bank 2014*e*). Because of the length of the time series and accessibility of other data, the focus in this case study will be on the U.S. military spending. Based on this data, research towards the two requirements was done.

Requirement 1

As figure 7.48 shows, two of the three peaks in outlays U.S. national defense fall together with major wars in which the U.S. was involved. That the peak is actually caused by the war and not by other external factors, is shown in figure 7.49.
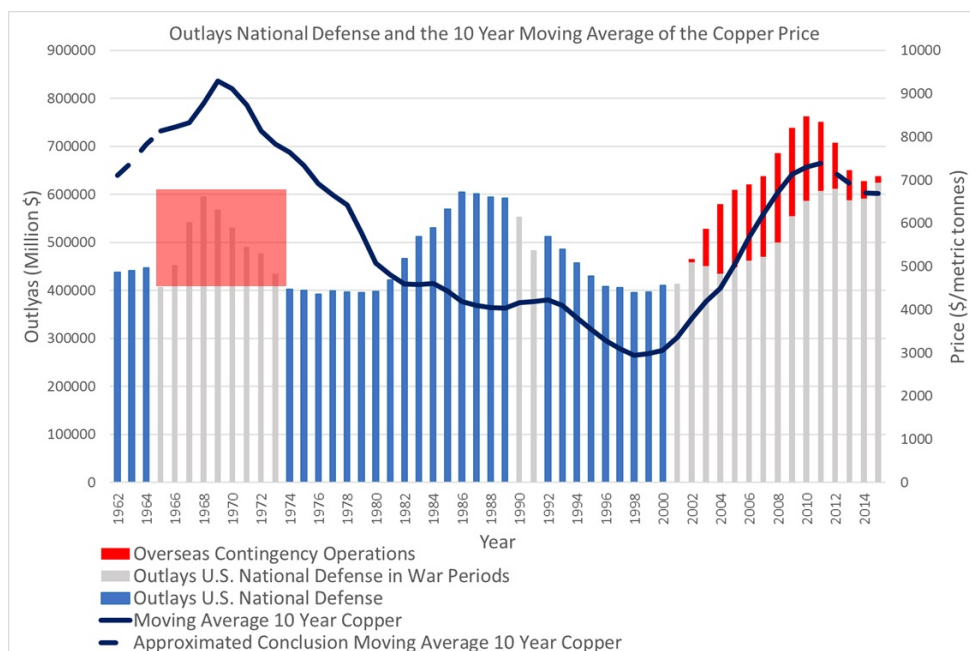
Figure 7.49: The red box encloses an equal sum of expenditures as the estimated costs of the Vietnam War (Congressional Research Service 2010). The costs for the wars in Afghanistan and Iraq are published in more detail and are, as part of the annual outlays of U.S. national defense, coloured red (Council on Foreign Relations 2015).

Over the last decade extra annual expenditures were implemented for ongoing war activities. Until 2009 known as 'supplemental', later renamed as 'overseas contingency operations'. Unfortunately, this detailed information is not available for the Vietnam period. However, a total estimate is given of 800 billion dollars (Afghanistan and Iraq combined was 1.6 trillion dollars). The red box, shown in figure 7.49, encloses an equal sum of expenditures as the estimated costs of the Vietnam War (Congressional Research Service 2010, Council on Foreign Relations 2015). Both situations show that the wars are, for an important share, responsible for both peaks [1].

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[1]Wars are an extreme form of manifestation of conflicts and their need for resources could affect the copper market significantly. But wars are not necessarily the only confict related factors that have attributed to an increase in demand for copper. In reaction of the 9/11 attacks, the Homeland Security was formed. Once completed, the department received 40-50 billion of dollars annually (Department of the Air Force 2005). Those kind of responses to conflicts, could affect the copper market just as well

Requirement 2

For the second requirement, the defense outlays in the U.S. are broken down into 6 main categories:

- Military Personnel
- Operation and Maintenance
- Procurement
- Research, Development, Test and Evaluation
- Military Construction
- Family Housing

Most expenditures (roughly 40% in 2011) go to Operation and Maintenance (O&M) (Department of the Air Force 2005), which covers major equipment (including spare parts and supplies), other equipment and supplies, and costs related to maintaining utilities and infrastructure (EDA 2016). This would a important part in which copper is used. Another category which would create a demand for copper is the procurement, which also covers the procurement of ammunition (Office of Management and Budget 2015).

Unfortunately, precise data on the use of copper in military equipment is unavailable in the sources used for this research. This could be for reasons, such as patents or keeping strategic issues a secret. However, parallels could be made with other industries. For instance, military vehicles would require more copper for heat exchangers, just like heavy duty or off-road vehicles do (Finnradiator 2016). Furthermore, the application of high-technology features in the army is also a good driver for the demand of copper (Copper Development Association Inc. 1999*b*). So for those reasons the time series was broken down and the focus shifted to the spending in O&M and procurement, visualized in figure 7.50.

7
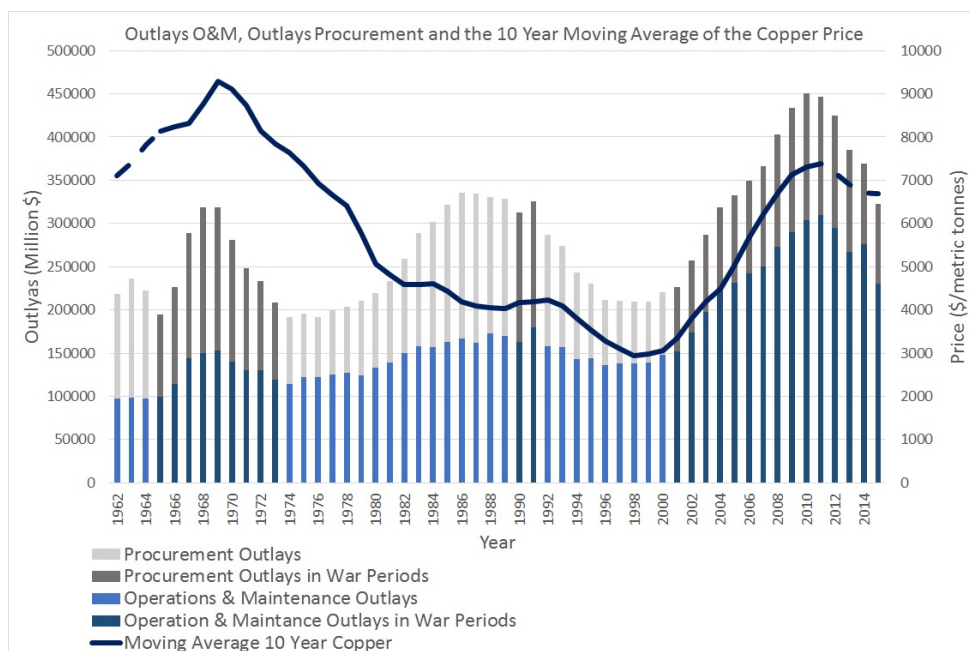
Figure 7.50: The part of the national defense outlays of the U.S., which is issued in 'operation & maintenance' and the procurement. Years with major U.S. involvement in wars are highlighted in dark grey/blue.

As can be seen in the figure, is the peak of Reagan's Build-up assignable to the procurement and less on O&P. Expenditures in O&M and procurement seem to have a clearer correlation with major wars. The first Gulf War also jumps out in the time series. For the procurement however, a more detailed analysis would be necessary. A reason could be that the spending on procurement during the Reagan's Build-up was more research related, instead of war related.

Interpretation
Calculating a correlation between the copper price and the outlays and wars, would not be reliable, due to the expansion of the copper market and the completely different dynamics of both time series. However, by giving a better look on the trends and the role of copper in military features, the statement can be defended. Both the ten year moving average of the copper price and the defense outlays peak in the same years as the major wars. Furthermore, the slopes have more or less equal gradients. Only in periods with the absence of a major war the correlation seems to become faint.

Conclusion
A substantial part of the expenditures in the military defense requires the use of copper

and has therefore influence on the copper market. However, this influence is minimal in times with an absence of wars. In periods with wars, an increase in spending in Procurement, Operation and Maintenance is required. Those are likely to be large and copper demanding divisions, for example due to the use of bullets and heavy equipment. As history shows, the Vietnam War and the Afghan and Iraq Wars combined increased the demand for copper and contributed in the rise of the copper price.

Over the whole time series, military spending in the U.S. increased and the expenditures during the Vietnam War are small compared to the outlays nowadays. This raises questions for the reasons and what the impact can be on the use of copper. Is this due to an increase in the level of technology used and does this mean that a war of the same size, or even smaller, can influence the market with the same impact as the Vietnam War did?

7

CASE STUDY: RESTRICTIONS

Introduction

Since 2005 the OECD has observed a strong increase in restrictions on industrial raw materials imposed by dozens of nations. This observation is shown figure 7.51(OECD 2014).
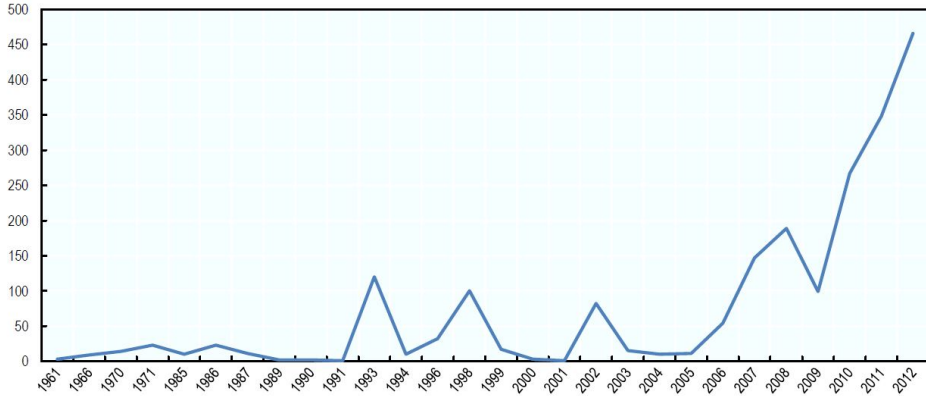
Figure 7.51: Restrictions on raw materials. Expired and reintroduced restrictions are counted as new restrictions (OECD 2014).

Export restrictions could be imposed for several reasons. One reason could be that a country believes that they need all resources and they can't afford to export the resources.

The consequence is that other countries believe that they are put in an unequal position, in which they export their resources, but are not able to import other necessary resources. Because of this, another nation would impose export restrictions by themselves. This could lead on to a situation in which several export restrictions could follow each other (OECD 2014).

In general trade measures block free trade and can cause trust issues between nations. Almost non of the restriction counted is related to the copper industry. However, the problem is identified as a serious issue that concerns the commodity markets. It could affect the copper market in the future. The possible consequences of those restrictions are illustrated in the case of the Rare Earth Crisis that started in 2009.

Rare Earth Crisis

As a form of resource nationalism, China put export restrictions on the rare earth elements, starting in 2007 and increasing every year. Due to China's monopoly[1] on the global supply of these elements, the measures had an incredible impact on the price of rare earth elements. Starting to rise in 2009, the price of some elements reached a peak in 2011 of 1000% of its initial price (Neodymium and Cerium). Mines were started and

reopened and the price dropped just as fast as it had risen, although the prices remained, relative to pre-2009, high. Later had China to withdraw the export restrictions by order of the World Trade Organization (Voncken 2016).

The chain of events, set by China, resulted in an extreme deviation from the long term consensus of the rare earth prices. However, the supply in most commodity markets is less unequally distributed, which prevents it from the happening of those extreme deviations.

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[1]97% of the 2005 global production is from China (Voncken 2016).

7

CASE STUDY: GOLD CORRELATION AS INDICATOR FOR POLITICAL RISKS

Introduction

Unlike oil, the gold market is not subject to political power-plays, like the two oil crises. Furthermore, the demand for gold, is much different from the demand created by oil and copper. Gold is considered a safe haven during uncertain times and this is the main driver for the demand for gold (Investopedia 2016*l*). Therefore, the relation between copper and gold could indicate how copper reacts to political risks in the world.

Objective

Is gold a good indicator for political risk and how does this relate to copper?

Data

Figure 7.52 shows how the real copper and gold prices moved over the last 55 years. The U.S. recessions are highlighted and represent periods of high uncertainty (Macrotrends 2016*b*).

Figure 7.52: The time series of the real copper and gold prices over the last 55 years. The U.S. recessions are highlighted and represent periods of high uncertainty. Furthermore are six key moments numbered (Macrotrends 2016*b*).

As can be seen there is only a rare correlation between recessions and the peaks in the gold price. To explain the role of gold as a safe haven, six key moments are marked (USGS 2010*b*):

1. The private and the official market become separated. Member central banks continue to buy and sell among themselves, while the official market becomes subject to supply and demand.
2. The release of the official market, a recession and the oil embargo are causes for a peaking gold price.

3. Start of the Soviet-Afghan war, the revolution in Iran and the 2nd Oil Shock drive the gold price to historical high levels.

4. Concerns about U.S. budget deficits and U.S. private- and Third World debts. Those are followed by the Soviet withdrawal from Afghanistan and the dissolution of the Soviet Union, causing a decade of relative low and stable gold prices.

5. In advance of the terrorist attacks of 9/11 a long term relative low is reached. After 9/11, the gold price maintains an upward trend for over a decade.

6. The European Debt Crisis causes a lot of concerns about the stability and future of the Eurozone (ECB 2016). The high gold prices can not be assigned to the crises in Ukraine and middle east, because those started at the end of 2013 and during 2014.

Apart from the first key moment, in which the change of pricing is noted, all share a similarity that they are founded on political events and risks. Based on this simplified analysis, one can say that gold is the indicator for political risks. Now a rate or form of a correlation with copper can be determined.

Correlation and Causalities
To start with the rate of correlation, which is 0,40 for the period 1970-2015. The sixties are ignored due to the different pricing system at that time. A correlation of 0,40 means there is a weak form of correlation present. This could indicate that both metals can be affected by similar events, but not exclusively. Think of wars, as is just stated for gold and as it is explained for copper in section 7.6.1.1. To show periods of a high and low correlation, the moving correlation method is applied (as explained in section 3.3). The result is shown in figure 7.53.
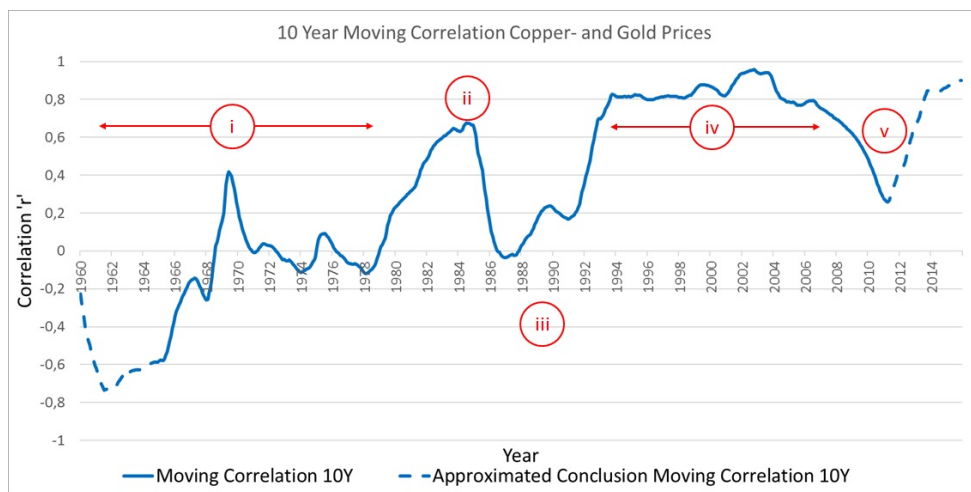
Figure 7.53: Moving Correlation copper and gold prices. Five moments and periods are marked, which are further explained.

Five periods are marked. The form of correlation or causality is addressed as follows (USGS 2010*b*, Edelstein 1998, 2010):

   i. No correlation: this is mainly due to the fact that the pricing of gold was controlled until 1968.
  ii. Strong correlation: while the gold price rises due to political instability in the world and the start of the Soviet-Afghan war, the copper consumption is at record highs.
 iii. No correlation: unrest on the economic markets caused a rise in the gold price, while consumption of copper is weakened. Following this unrest, the cold war ends and the new state of political stability drives the gold price down, while copper consumption is pushed up, due to an improving economy.
  iv. Strong correlation: long term stability in the world, followed by multiple wars occur parallel to respectively a stable and unstable copper market.
   v. Weak Correlation: an economic crisis and the European Debt Crisis cause an strong price rise for gold, while the markets cool down and copper consumption decreases fast.

The general outline of the relation between gold and copper for these five moments and periods is varying and can be positive or negative. The arguments made in these outlines, could strengthen the arguments made in section 7.6.1.1, which explains the relation between copper and wars. As the gold price is high, or is rising, due to a war, copper consumption tends to do the same. Due to the demand of copper in wars, this can be considered a causality. However, if stabilization or political crises occur, prices seem to have an inverse correlation. For copper, this is due to a weakening economy.

Gold as Early Warning Indicator for Copper
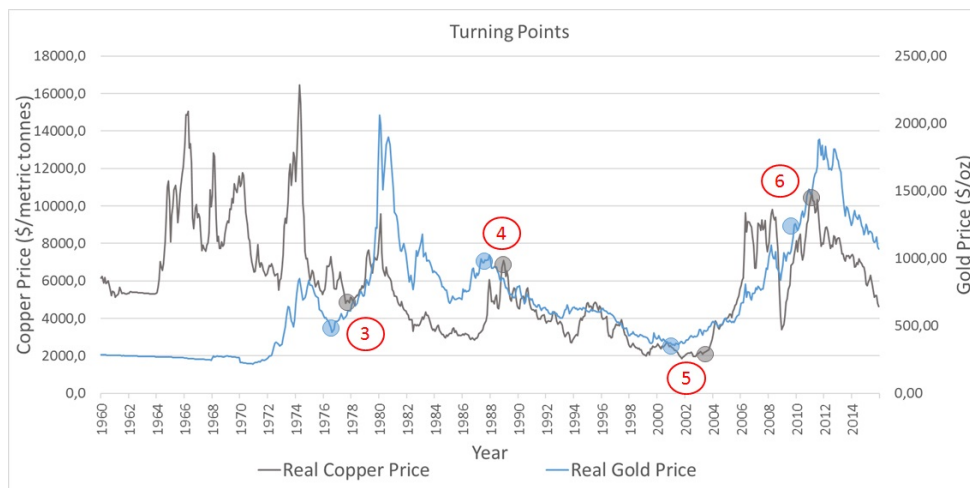
Figure 7.54: The turning points in the time series of the copper and gold markets, which are caused by the main events discussed, are highlighted.

Another interesting observation is that for most main events discussed, the turning points, the peaks and troughs, for the gold price precede the turning points for the copper price. The turning points are highlighted in figure 7.54.

The gold price, as an indicator for political risk, is much more subject to global developments. Copper however, is subject to actual physical changes to demand and supply. Because of this difference, the gold price reacts must more rapidly on an announcement of stabilization or a declaration of war. This can be clearly noticed at the start and end of the Soviet-Afghan war (number 3 and 4) and at the 9/11 terrorist attacks (number 5) (USGS 2010*b*, Edelstein 2010).

The situation after 2010 (number 6) however, is more complex. At the moment the wars in Afghanistan and Iraq were scaled down (2010-2011) the European Debt Crisis (2009-2013) took over. Both events drove the gold price up, but had an opposite impact on the copper price. Strengthened by the slowing of the Chinese Economic Boom, copper made a downfall shortly after (end of 2011) (Council on Foreign Relations 2015, ECB 2016).

An exception of this observation is the effect of the 1973 oil crisis, which was preceded by the nationalizations and revolution in Chile. This unique event only affected the copper market and disturbed the correlation (Edelstein 2010).

Conclusion

Gold and copper will never be directly influenced by each other, but seem to be strongly affected by similar types of events. A detailed analysis of those events is necessary, because different events can cause the same impacts on the gold price, but opposite effects on the copper price.

Because the market for gold reacts directly on developments in the world, and copper only on physical changes in supply and demand, it precedes movements in the copper market. Those indicators can be both very clear and very complex. However, some awareness is required for developments, which are overshadowed by purely copper- or gold related events. To conclude, gold seems a very good indicator for long term trends in the copper market.

7.6.2. CONCLUSION

The global copper market, is easily affected by global conflicts. Those conflicts can be in the form of confidence crises in the international community, also in the form of wars. A necessity is, that a conflict has a physical impact on the demand or supply. A war for instance, which requires a limited amount of copper, or a restriction, that affects a different commodity, won't affect the copper market significantly.

Gold appears to be a very good early warning indicator for long term trends. It reacts

directly on global developments, where copper reacts on physical changes in the supply and demand. A detailed analysis of the trends, causing price difference in the gold market, is required. This is because the copper reacts variably on certain events, which cause same impacts on the gold market.

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DISCUSSION

8.1. INTRODUCTION

So far, this study has identified indicators and signals, which were associated with the historical events and developments. Most of this is based on historical grounds. This chapter will discuss the validity of the results. First, a small is summary given of the identified indicators and signals of the specific category, followed by a discussion of the results.

This discussion will introduce a perspective, which determines the likelihood of the changing relevance of each indicator. Will an event or development, which affected the copper market fifty years ago, affect it nowadays? This chapter will also discuss current developments, emphasized with identified indicators, which could affect the copper market in the upcoming months or years. By the end of this chapter, one can determine the validity of the answer to the research question as initially stated in the introduction (chapter 1).

- Identification of indicators, signals, events and developments which improve the understanding of the dynamics of the copper market.

8.2. METHODOLOGY

8.2.1. DISCUSSION

The results of the proposed methodology have been analysed in this thesis. Advantages and disadvantages were recognized. The advantages of the methodology are:

- The moving average method proves to be an easy way to separate events and developments of different time spans. By calculating the surprise component, an event's impact can be approximated.
- The method could well be applicable for all commodities.
- The causal relations between events, developments and the copper market, proof that the results of the methodology concern events and developments that affected the market significantly.

During the analyses of all the results, some shortcomings appeared. These disadvantages are:

- The methodology can't separate the impact of two events or developments of similar time spans. Examples are: The Vietnam war versus the OECD postwar economic boom in the sixties and the Afghan and Iraq wars versus the China economic boom in the early 2000's. Because of this, these developments can't be fully assessed on the impact they actually caused solely.
- The categories may not be sufficiently defined. A lot of interdependencies appear to exist between the indicators and categories. One can think of how wars and conflicts are assessed on the demand they create, but the accessibility of a region could be determined by the same causes. Other examples are the indicators for an economic boom, which are just as important for the supply and demand for copper in general.
- The methodology only results in a relative ranking. The value of the impact is an indicator and is therefore only a approximation of the impact. An exact value can't be measured, due to a psychological factor.

8.3. SUPPLY AND DEMAND

8.3.1. SUMMARY

The following indicators and signals are identified and used to represent the category 'supply and demand':

- Company strategies indicate how companies are investing in the copper industry and how the supply stream will develop over time.
- When the commodity cycle hit its peak, the likelihood of strikes increases. This is due to the employees' desire to get a larger share of the revenues. If several major mines are faced with strikes, supply disruptions could occur; combined, they are big enough to affect the copper market significantly.
- The goal to establish a sustainable society will have large consequences on the copper demand. Copper is an essential metal for sustainability, due to copper's characteristics. Furthermore, the desire for a sustainable society will also increase the incentive to recycle and to increase its supply.
- Inventories vary over times and follow commercial principles. Increasing or decreasing inventories go parallel with respectively a fall or rise in the copper price. Occasionally inventories are going down, before the copper price starts to (rapidly) rise.
- The shape of the cost curve, can indicate how volatility changes, relative to the immediate past.

8.3.2. DISCUSSION

Strategies indicate how prepared suppliers are for meeting future demand. But eventually, it will be future events, which show how convincing these strategies were. If copper demand events fail to come, structural oversupply will start to exist. On the contrary, if a new economic boom occurs, it could be revealed that the strategies were insufficient.

Besides a conventional driver like economic growth, which is discussed in section 7.3, sustainability is recognized as a new driver for demand for copper. Although the impact of sole developments, like the rise of the electric vehicle, fall short[1], the impact of a group of developments could possible result in a significant rise in demand for copper. One can think of other sustainable developments like solar cells and wind turbines (Copper Development Association Inc. 1999a).

The lift-off of a real and significant development towards sustainability might be well described by Bloomberg (2016). Bloomberg appeals to the theory of the S-curve in which old technology is replaced for new technology. The example follows the rise of the electric vehicle, which starts slowly, but of which it is expected to undergo an accelerated growth as the technology improves and matures. The theory might be applicable to many more forms of new sustainable technologies which together could affect the demand for copper significant.

8.4. MARKETS

8.4.1. SUMMARY

Events and developments on other markets seem to affected the copper market as well. Recognized indicators are:

- Uncertainty on the financial markets does not necessarily affect the copper market. However, if the uncertainty is caused by a recession, it will cause a fall in demand and consequently a fall in the price.
- Normally, oil does not affect the copper market. Periods of extreme oil prices resulted in a small increase of marginal costs, which could have had a benefit in a price peak for copper. However, several other reasons can be stated, which could have affected the price significant.
- When the U.S. Dollar Index (USDX) is high, copper becomes more expensive in non-dollar currencies which results in a weakening demand. On the contrary, it takes more dollars to buy copper, when the USDX is low. This boosts the price. The USDX itself and events/developments affecting the USDX are considered to be very important to the copper market.

8.4.2. DISCUSSION

The influence of a recession on the copper market is expected. As stated in section 7.3, which discussed the indicators related to the occurrence of an economic boom, copper demand is dependent on the growth of an economy. Because a recession means that the economy is contracting, copper demand would do the same. Therefore, future recessions continue to be events, affecting the copper market significantly.

History proves that extreme oil prices affected the copper market slightly. However, this thesis does not seek to analyse the significance of the effect of the recent oil price peak. The marginal costs of copper did rise, but besides the high oil price, other causes can be stated, such as a weakening incentive or practicability to decrease the marginal costs. Future developments and researches will provide a better understanding of the

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[1]The most optimistic scenario predicts for 2040 an 1-2,2Mt increase in demand for copper (Nasdaq 2016).

causal relation between the oil and copper prices in the early 2000's.

The aftermath of the vote of Great Britain leaving the European Union, a process that could take up years, will be a determining event for the significance of the USDX as indicator for copper. Great Britain leaving the European Union could create uncertainty on the European markets and could weaken both the euro and pound sterling. The currencies combined have a large weight in the value of the dollar and could cause a strengthening USDX (together the two currencies have a weight of almost 70%). Because copper follows the dollar fluctuations closely, a strengthening dollar would hit the copper price significantly (The Economist 2016, Financial Times 2016). However, currently are the consequences of the aftermath not clear. The USDX, which was already relatively high for a year, did not rise significantly (Macrotrends 2016*c*) and the economic consequences are not clearly visible. The effect of the exit could turn out better than expected or could be delayed.

An argument against the significance of the USDX can be made for the lack of variation in currencies used in the index. Only six currencies are used in the index, namely the euro, Japanese yen, pound sterling, Canadian dollar, Swedish krona and Swiss franc. As can be noticed, the currencies of newly risen economic powers, such as the Chinese yuan renminbi, are not included. An alternative index for the USDX, is the trade-weighted dollar currency index, which value is based on 26 currencies (Investopedia 2016*i*). In this index the share of the Chinese yuan renminbi is higher than the euro. Furthermore, the euro and pound sterling combined, have only a share of less than 20% (Federal Reserve 2015). In a world with many upcoming economic powers, it could be likely that the trade-weighted index will take over the role of the USDX. Therefore, events affecting e.g. the political stability in Europe, will affect the copper market less. On the other hand, Chinese events are not ignored any more in the strength of the dollar.

8.5. ECONOMIC BOOM

8.5.1. SUMMARY

One development with the ability to boost the copper market is the occurrence of an economic boom. Examples are the postwar economic boom (60's) and the China economic boom (2000's). The following signals and indicators of this development are recognized:

- A signal for the likelihood of an upcoming economic boom within a nation or a region could be its adaptation of free-market principles.
- A GDP growth in the range between 0 and 20,000 U.S. dollars at PPP per capita, will cause the most effect in the use of copper per capita. This is because copper is an important metal in making it possible to provide a population with its basic needs, such as electricity and energy. The status and significance of an economic boom, within a nation or a region, depends on the GDP and its status in e.g. the following indicators:
  - Energy use
  - Access to electricity
  - Rate of urbanization

8.5.2. DISCUSSION

This thesis has recognized important indicators and with this information, the significance of a region with economic growth can be determined. An observation made in section 7.3.4.1, is China's limited potential to increase the global copper yearly consumption by only 2Mt of copper, while India and Sub-Saharan Africa could boost up the copper consumption by 8-9Mt of copper each (The World Bank 2004, 2012, 2014*b*, Rio Tinto 2009).

Currently, India is experiencing the highest economic growth in the world (McKinsey 2016*a*). In September 2016 this believe of India's future significance was strengthened by a podcast from McKinsey (2016*b*), which states that the trend toward urbanization and an increase in power consumption will boost India's economy. Both indicators have clear causal relations with an impact on the demand for copper.

Also Sub-Saharan nations are growing economically, due to the implementation of free market principles over the last decade. The potential is clear, but signals for the start of a new economic boom in Sub-Saharan Africa are not identified.

As is shown, economic growth is a very significant indicator for future copper demand, but the current economic development in large regions of the world do not show a boost (yet). Therefore, Rio Tinto's prediction of an consumption growth of 1Mt per 15 months (section 7.1.1.1) (Rio Tinto 2016*e*), could end up in disappointment.

8.6. TECHNOLOGY

8.6.1. SUMMARY

Technology can enable new forms, origins or alternatives for copper. Signals and indicators are identified within the technological development:

- The potential of deep sea technology is illustrative for future new sources of copper deposits. Technology enables a continuous growth of copper reserves in terms of exploring a larger region for new deposits. Real indicators do not seem present yet, but the development does express in signals, such as news and reports.
- Improvement of already existing technology and the development of new technologies could enable companies to extract ore of lower grades and ore from deeper levels. This results in a continuous growth of copper reserves in terms of extracting ore, restricted by less constraints.
- Recycling remains to be used in limited matter. A trend break is identified, and the recycling efficiency rises. However, a majority of available secondary copper is still going to waste.
- Substitution does not yet challenge the choice for copper. The characteristics for copper favour sustainability, energy efficiency and high technology products.

8.6.2. DISCUSSION

After a decades long decreasing trend of marginal costs, a trend break occurred in 2001 and marginal costs started to rise. This could be due to the weakening of both the incentive and the practicability to minimize marginal costs. But no matter the cause, technological progress has experienced a change of dynamics.

Technological challenges are identified in companies, which need to choose for moving operations to relatively unstable areas or choose for deposits which are often located deeper and/or have lower grades of copper. However, as shown in section 7.5, the relatively unstable regions tend to become more stable and production is picking up again in regions like the African Copperbelt (figure 2.11).

Opportunities and technological developments in non-flotation technologies, such as solvent extraction, are promising. Innovation and the development of new flowsheets result in the ability to lower marginal costs, causing operations to move down the cost curve. Solvent extraction is a commonly used technology in the African Copperbelt (Sole & Tinkler 2014). Although there are many challenges, which still need to be overcome[1], this development will be another advantage for the future of the African Copperbelt as a copper producing region. Researchers even suggest that current operations and planned expansions will develop the Copperbelt to the largest copper producer of the world, provided that the period of relative stability continues (Sole & Tinkler 2014).

Furthermore, alternatives to conservative ways of supplying copper are researched, e.g. recycling and substitution. Of those two, copper recycling appears to be an underdeveloped industry. Driven by the motivation to establish a sustainable society, copper recycling is likely going to experience a boost and should take a larger share in the future supply of copper.

The change of dynamics in technological progress results in the identification of many new challenges, which have the ability to affect the market significant. Therefore, the discussed signals and indicators will remain to be relevant for the upcoming years.

8.7. ACCESSIBILITY/AVAILABILITY

8.7.1. SUMMARY

The investors climate is a heavy constraint on the supply of copper. Mining of a certain region is seriously affected by a bad investors climate. Indicators for the investors climate are the fragility of a state and the discount rate, defined by e.g. the following parameters:

- The fragility index is an indicator for either the stability of a state, as well for the likelihood that a nation (de)stabilizes. Risks and opportunities can be identified in weak nations which could respectively destabilize.
- The discount rate can be broken down to many parameters. The following parameters are considered to be dependent on the investment's location:

    - Corruption
    - Likelihood of nationalizations
    - Tax policy
    - Environmental laws and human rights issues

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[1]Challenges such as improving the power supply and logistics, fight against corruption, hiring a skilled workforce and difficult government regulations and legislations (Sole & Tinkler 2014).

8.7.2. DISCUSSION

The fragility and discount rate are extensively discussed in section 7.5. Also case studies are used in this section, which show that the relevance of the indicators continues to the present day. The current stabilization of the Copperbelt region illustrates an example of a currently ongoing development affecting the copper market significantly. Looking at figures 7.45 and 2.11, copper production and the stability of a region have a strong relation. The stabilization of the region has resulted in a production, which is picking up again.

8.8. WAR/CONFLICTS

8.8.1. SUMMARY

Political and military conflicts have proven to affect the copper market significantly. The following events and developments are identified:

- Major wars, such as the Vietnam War and the two wars combined in Afghanistan and Iraq, require the use of copper, large enough, to affect the copper market significantly. This is because of the use in applications, such as bullets, heat exchangers in heavy duty equipment and high technology features.
- Political risks harm the trust of investors and consumers, which affects economic growth negatively. The consequence is a decrease or weakening growth of the demand for copper.
- Although they did not occur yet, export restrictions on commodities are identified as a potential threat to the supply of copper. This is because restrictions are blocking free trade.

The price for gold is recognized as an indicator, from which the significance of a war or political risk could be derived. This is because the dynamics of the gold market, are also based on speculation, while the copper market mainly follows the commercial principles. This results in a copper price that only reacts on physical changes in demand or supply, which has a delayed response on political events. The measure in which the gold price rises or falls, could be an indication for the significance of an event and its effect on the copper market.

8.8.2. DISCUSSION

In times of war, U.S. defense outlays appear to be good indicators for the copper market. The outlays give an indication of the magnitude of the war and when the magnitude is large enough, the wartime demand tends to be large enough to increase the demand for copper. In times of an absence of a large war, no causal relation can be made between the outlays and the consumption of copper. An opposing argument for this indicator can be made. As the global copper market becomes bigger, the expenditures in a future war need to become higher as well. This, and the likelihood of new future wars in general, is not further researched in this thesis, due to the complexity of warfare which demands knowledge in other fields of science.

Gold is recognized as indicator for the impact of wars and for political risks. This is not expected to change, as long as the gold market remains to obey commercial and

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speculative principles, while the copper market remains to follow commercial principles.

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9

STRATEGY

9.1. INTRODUCTION

This study provides an identification of events and developments, which affect the market significantly, and shows the associated indicators and signals. This chapter will discuss two forms of strategies which could be derived from this information. One is based on reacting on likeable scenarios, the second is based on risk mitigation. Furthermore, strategies are discussed for each stakeholder.

To start with, two likely scenarios are made for the direction the copper market is heading to. The goal is not to make hard predictions, but to make a basic and underlying assumption, from which can be explained how to use the information that is provided by this thesis. Afterwards the two scenarios will be discussed in the perspective from some stakeholders. Which scenario is best for the specific stakeholder, how can they ensure that this scenario will be the eventual outcome, how can they maximize benefits from this.

The second use of this information is in the optimization of risk analyses throughout the value chain. All stakeholders within this value chain, can therefore identify high risk elements and can insure and protect themselves from those critical links.

9.2. SCENARIO'S

All events and developments were ranked according to the significance of impact they had (chapter 5). The results were shown in table 5.1. Although all the events caused some fluctuations on the market, only three categories are recognized which were significant enough to determine the long term trend. Those were:

- War/Conflicts
- Technology
- Economic Boom

The relevance of the categories of today is discussed in chapter 8. Some observations on these categories are:

- **War/Conflicts**: Wars have a positive effect on the demand for copper. A recent signal, which warns for an upcoming war, is not identified. Within the part of conflicts however, a development of improving stability is recognized in the African Copperbelt. Because it concerns a copper rich area, this development will have a positive effect on new supply of copper.
- **Technology**: Technology has a positive effect on the supply of copper. Technological progress, in the form of innovations in new supply streams or processing technology, cause a decrease in marginal costs. Consequently the supply rises and the actual price falls. Recent innovations and developments occur in the solvent extraction technology, which is used commonly in the African Copperbelt.
- **Economic Boom**: An economic boom has a positive effect on the demand for copper. Although potentials booms are recognized, this thesis did not identify a signal for the start of a new boom.

Some clear current developments are recognized which could secure a stable supply of copper for the upcoming years. There appears to be more uncertainty on future demand for copper. Referencing to the short observations stated above and the discussion of all indicators and signals in chapter 8, two scenario's are set:

- **Scenario 1**: A combination of improving stability in the African Copperbelt and further innovation in solvent extraction, strengthened with a strategic shift into copper by mining companies, will cause a stable and secure supply of copper for the near future. On the demand side is more uncertainty. A new economic boom or a new period of a high wartime demand seems unlikely. A massive embracing of new sustainable appliances in both recycling and consuming energy, will happen, but not in the next few years.
- **Scenario 2**: A combination of improving stability in the African Copperbelt and further innovation in solvent extraction, strengthened with a strategic shift into copper by mining companies, will cause a stable and secure supply of copper for the near future. A new period of high wartime demand seems unlikely. But the next economic boom is upcoming. This will be strengthened by a massive embracing of new sustainable appliances in both recycling and consuming energy.

Both sketched scenarios appear to result in two very opposite price scenarios. A reason can be found in whether an economic boom or sustainable transition occurs or not. The characteristics of such a development are widespread to the value chain, affect the whole society and are driven by a strong economic force (section 7.3). Thereby, potential economic booms, which seem to be most likely to occur, are India and Sub-Saharan Africa. Both are regions with a population of roughly 1 billion of people and with a relative low standard of living.

9.3. STAKEHOLDERS

9.3.1. MINING INDUSTRY

Key Indicators: U.S. Dollar Currency Index, Discount Rate, Economic Indicators, Innovation New Technologies, Company Strategies, Supply Disruptions

Producers of primary copper will benefit the most from a tight market scenario in which prices rise and their returns increase. However, if the price rises too high, it would show that the companies were not prepared, it can cause extra volatility and it would boost alternative supplies, like recycling. It is most likely that supply shortages arise out of an accelerating economic growth in a region such as India and Sub-Saharan Africa. To foresee an accelerating economic development in these regions, producers need to monitor economic indicators, e.g. access of electricity and urbanization.

A challenge for producers will be the making of a trade-off. They will need to choose between mining deposits with more complex extraction methods and mining in relative unstable regions. Monitoring the fragility index and discount rate, will help producers to balance this trade-off. In both situations, producers are required to remain competitive with alternative supplies, no matter how tough the challenge is. Such an alternative is recycling, mainly because its large potential.

Besides remaining competitive, companies need to minimize the capital and operational costs within a project, so they become resistant for a potential upcoming period of lower prices. Finally, producers need to monitor political and economic events and developments, which could affect the value of the U.S. dollar. Especially, due to high uncertainties in Europe, the high value of the U.S. dollar could be a significant factor in future prices of copper.

9.3.2. RECYCLING INDUSTRY

Key Indicators: U.S. Dollar Currency Index, Discount Rate, Recycling Efficiency, Sustainable Transition Indicators

The big advantage of the recycling industry is that it is free of making a trade-off between a complex mining operation and the extraction of copper in relatively unstable regions. Besides this, the industry is also driven by the sustainable transition. So, not facing human rights and environmental issues, the recycling industry can benefit from a high social acceptance.

The rate of recycling efficiency, the share of the total amount of scrap which is actually used for recycling, was still low (33%) in 2013. This thesis does not cover the reasons why it is low. But it seems likely that the industry is financially or technologically not mature enough. If the industry wants to compete to primary supply or wants to sustain a period of low returns, it needs to optimize the processes throughout the whole value chain.

Concluding, the recycling industry is faced with the challenge to develop further and mature. The discussed indicators and signals can be used as opportunity. For example, monitoring the indicators related to the sustainable transition can be used in lobbying new recycling friendly policies or funds in research and development. If the recycling industry succeeds to develop further, it will be competitive in a scenario of low returns and provide as an extra supply stream in times of deficits.

9.3.3. CONSUMING INDUSTRIES

Key Indicators: Fragility Index, Company Strategies, Sustainable Transition Indicators, Recycling Efficiency, Economic Indicators

To ensure a stable supply of copper, the consuming industries are best off, when they start to demand products with an increased amount of secondary copper. Although this transition can't be done immediately, it will stimulate the recycling industry to do research and to develop. When more recycling companies enter the market, an incentive will arise for innovation and competition. A successful innovation and competition from this industry will be less sensitive to supply disruptions and environmental and human rights issues. This would benefit the consuming industries.

The scenario may be that large supply deficits occur. Consumers will face high and volatile copper prices. To foresee these situations, it is best to monitor the presented indicators which could point out an upcoming economic boom or warn for supply disruptions. If the copper consuming industry is able to foresee supply disruptions or rapid price rises, they could ease the effects by the strategic stockpiling copper. Furthermore, risk identification can help to forecast periods in which phenomenons, such as copper theft, revive. Following, they can insure and protect themselves. Although substitution seems a solution which is unlikely to be successful, it can not be ruled out. Further research in substitution could result in a measure against volatility and scarcity.

9.3.4. GOVERNMENTAL
Key Indicators: Recycling Efficiency, Fragility Index, Sustainable Transition Indicators, Innovation New Technologies

Low costs for resources, such as copper and energy, help maximize the value of a society's output, especially when it is considered a non-resource rich and mature country. To minimize the prices, governments need to ensure a stable supply of resources. Those governments have only a limited number of options and are dependent on resource rich countries. To avoid this, nations need to become more self-sustainable. Options are to install policies with the goal to create alternative sources of copper. Furthermore, governments could fund research towards recycling and substitution.

Because of the low recycling efficiency, a large potential source of copper is identified in the recycling industry. By implementing policies, governments can stimulate the recycling industry to optimize their value chain. Not only economic reasons should motivate governments for stimulating recycling, also environmental reasons. So while the market is relaxed and prices drop, sustainable goals are achieved as well.

A consequence of the sustainable transition is the effect on the demand for copper. Copper will, due to its characteristics, be an essential metal in sustainable appliances. While the supply of copper is increased, because of recycling, the demand for copper increases as well. So sustainability will not only result in an increase of supply, but as well in an increase in demand, which needs to be met.

Another possibility to ensure a stable supply of copper is to support Sub-Saharan Africa economic development. With this support, a stable source of Sub-Saharan African copper could be ensured.

The same region, will be a challenge faced by western governments. The ethical discussion arises for whether to support the underdeveloped region and ensure a supply for copper or block the supply due to either human rights issues. This issue is expanded

by the role of China, which gives Sub-Saharan nations the opportunity to borrow money, without qualifying for western requirements (Naidu & Mbazima 2008). Retreating out of the region, would mean that the region's opportunities to develop, are reduced. Continuing operations, will give a possibility to improve the situation. However, to make the issue more complex, this scenario will not benefit the transition to a self sustainable society.

9.3.5. INVESTORS
Key Indicators: Gold Price, Market Uncertainty, U.S. Dollar Currency Index, War Policies, Discount Rate, Inventories, Cost Curve, Supply Disruptions, Economic and Sustainable Transition Indicators,

It would benefit the investors most if a period of high returns is realised. However, the if and when are two unanswered questions. Investing in projects with the assumption that prices rise, could end up in disappointment. Therefore, investors need to take watch that the projects, financed by themselves, are enough protected for a period of low copper prices. In this scenario, projects need to be able to depreciate their capital costs, while paying their operational costs.

Future supply appears to be secure and stable, while demand is uncertain. Assuming that the start of a copper mine takes 10-15 years, investing in copper on the long term could be very lucrative. This is due to a continuous increase in demand for copper, which is likely strengthened by the sustainable energy transition.

On the short term it appears that an oversupply will rule the market. This makes investing in copper on the short term less profitable. This will change when the supply is disturbed or the increase in demand is accelerating. Monitoring indicators in the Copperbelt region, the sustainable transition and some specific economies, such as India and Sub-Saharan Africa, can help to identify the turning point.

9.3.6. OTHER COMMODITY INDUSTRIES
Other commodity industries are affected by many similar indicators, but also by commodity specific events or developments. Implementing the approach suggested in this thesis would help to understand the dynamics within the specific commodity market.

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CONCLUSIONS

CONCLUSIONS ON IMPACT ASSESSMENT

A new indicator was developed and used to determine the impact of historical events and developments. The events and developments with the most significant impact were of the following categories:

- **War/conflict**: Increase in demand caused by wars/conflicts
- **Technological Development**: Enables new copper supplies
- **Economic Boom**: Increase in demand caused by economic booms

Next are the categories of events and developments that caused the most extreme deviations between the actual price and expected price:

- **Supply and Demand**: Cyclical nature of the market causing supply deficits
- **Markets**: Financial crises have disturbed the demand for copper
- **Accessibility/Availability**: Rapidly transforming climate of investments in supply regions

The method has proven to be able to separate, assign and measure the actual impact of a happening, even when two events or developments of different time lengths are overlapping. However, this method shows limitations, when two events or developments of the same time length are overlapping. An example is the China economic boom, which is assumed to be the main cause of the high copper prices of the last decade. However, valid arguments can be made that the wars in Afghanistan and Iraq had a major influence as well.

CONCLUSIONS ON CASE STUDIES

Within these six categories of most significant events and developments, indicators and signals were identified, verified on their causal relations with the copper market and assessed on their significance. The following results are most worthy to mention:

- **Wars/conflict**: Major wars, such as the Vietnam War and the two wars combined in Afghanistan and Iraq, have caused an increase in demand. The intensity of the conflict is expressed in outlays in defense. When the outlays rise, copper demand will rise due to the necessity of the metal in new equipment. Furthermore, gold is a good indicator for political risk and it shows the seriousness of the situation in how it is perceived by the markets. Those two indicators tell in what degree it is likely that a future war affects the copper market.

- **Technological Development**: The development in the flotation technology has caused an significant decrease in marginal costs, even while ore grades were decreasing. This contributed to a decreasing long term trend of the copper price between 1970 and 2000. Nowadays signals are picked up showing that innovation and development of new flowsheets occur for an alternative processing technique: the solvent extraction and electrowinning. Another source of copper, recycling, shows a huge potential as well. The current recycling efficiency is low, but has been increasing significantly for the last decade, which indicates a rising supply from secondary sources. These signals and indicators show the trend of the technological development and could tell the likeable future of it.

- **Economic Boom**: Indicators, such as the use of energy, the rate of urbanization and the percentage of the population who have access to electricity, show clear causal relations to the copper market. It reveals that copper is an essential metal for the basic needs in a society. Therefore a GDP growth in the range between 0 and 20,000 U.S. dollars at PPP per capita, will cause the most effect in the use of copper per capita. Monitoring signals for an upcoming boom in regions, which are behind on those requirements, will tell how and when demand for copper could boost. Such regions are India and Sub-Saharan Africa.

- **Supply and Demand**: This category covers indicators of how supply and demand develop and how they balance. Most significant subtopics are how companies put down their strategies, how new uses of copper enter the market and the consequences of supply disruptions. The first indicator tells how the supply stream will develop in the future, while the second indicator tells how demand will develop in the future. An example for the latter is the rise of sustainable appliances and their need for copper. Finally, the peak of a supply and demand cycle is recognized as a critical point in which the likelihood for strikes increases significant. In that situation the occurrence of strikes can boost the copper price even higher.

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- **Markets**: Financial crises have caused occasionally a price shock in the copper market. An indicator for crises is market uncertainty. This appears to be a less useful indicator, high market uncertainties only seem to affect the copper market during a contraction of the economy. Besides the market uncertainty, other markets were researched, such as oil, base metals and the U.S. dollar currency index. Although oil is an important consumable in the extraction and processing of copper, only a slight impact is recognized in the time series of the marginal costs, which was caused by the two oil crises. Only the latter, the U.S. dollar currency index, has a clear relation with the copper market. If the index is high, then copper becomes

expensive in non-dollar currencies and weakens the demand. If the index is low, more dollars are required to buy copper and this boosts the price. Because of the correlation, all events affecting the U.S. dollar currency index are of importance.

- **Accessibility/Availability**: The climate for investment in supply regions is of a real relevance. Because of the unequal distribution of copper reserves throughout the world, disturbing or stabilizing events in copper rich regions could affect the market significantly. The best indicator for the climate for investment is the discount rate, and to be more specific, the included factors which depend on the nation. The best identified indicators are: fragility index, corruption, risk of nationalizations, tax policies, environmental laws and human right issues. Monitoring these indicators will tell how the climate for investment in copper rich regions develops.

DISCUSSION

In today's context, the relevance of some categories and their indicators and signals are either already debatable or already proven. An example for the first is the demand caused by wars. As the copper market grows, the size of wars also need to increase to maintain its impact on the market. On the other hand, Great Britain leaving the European Union, is an example which could cause a strong dollar for the longer term. This makes it an event that proves the relevance of the U.S. dollar currency index as indicator for the copper market. This research revealed that new drivers can enter the market. Think of new sustainable appliances and their need for copper, and old drivers could reduce, such as war demand.

CONCLUSIONS FOR THE RESEARCH

This research identified a set of predictors. This form of root cause analysis has enabled the determination of the impact caused by events and developments. By using the associated indicators and signals, the likelihood of an occurrence of a similar happening and the strength of its impact could be estimated. Strengthened by the assessed causal relations and significance, is this set of predictors a useful tool to foresee likeable future scenarios. The tool is more suitable than pattern recognition, because it can be used to identify the prelude of a normally random event. However, one big pitfall needs to be mentioned, which is the human component. The human aspect makes it impossible to predict the exact outcome, because the eventual impact of events and developments is subject to the human mind.

STRATEGIES

The outcomes can be used by a wide range of stakeholders in the copper industry. Indicators and signals, such as the U.S. dollar currency index, discount rate, fragility index and gold price can be used to optimize risk analysis. To bypass some of those risks, potentials are identified in alternative sources for copper, such as copper recycling and maybe in the long term even deep sea mining. The recycling efficiency rate is a clear indicator which shows the status quo of the recycling industry. Finally, sustainable energy transition, economy, company strategies and new innovations in processing and

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extraction technologies reveal information on the development of the balance between supply and demand. Depending of the objectives and values of the stakeholder, this set of predictors can be applied in optimizing their strategies.

RECOMMENDATIONS

For this research some recommendations are suggested. An encountered limitation was the categorizing of events and developments. Some categories overlap each other in certain topics, which could create some vagueness. Extra research in the newly developed indicator is also recommended. The indicator is not able to include the psychological factor, caused by the human component, and is not able to distinct events of the same length, occurring in the same period. Furthermore, follow up studies in a specific field of study (military, political and economic) will improve the set of predictors. Finally it is suggested to expand this research to other commodities.

FINAL STATEMENT

The proposed method is able to identify a set of predictors and will improve the understanding of current dynamics of the copper market. Strategies and risk analyses can be optimized by the use of this set. The advantage of the copper market is that it is mainly affected by physical changes in the supply and demand balance, rather than speculation. However, the human component adds a psychological aspect. This component is not eliminated and remains a pitfall, making the market extra complex. One should always be aware that new drivers will enter the market and old drivers could reduce. Updating this study will benefit industries, governments and consumers to remain prepared for future market fluctuations.

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RECOMMENDATIONS

Based on the encountered limitations of this research, some recommendations are made.

CATEGORIZING

The determination of categories could be improved. A lot of interdependencies appear to exist between the indicators and categories. One can think of how wars and conflicts are assessed on the demand they create, but the accessibility of a region could be determined by the same causes. Other examples are indicators for an economic boom, which are just as important for the supply and demand for copper in general.

BREAKDOWN OF EVENTS AND DEVELOPMENTS

The methodology can't separate the impact of two events or developments of similar time spans. Examples are: the Vietnam War versus the OECD postwar economic boom in the sixties and the Afghan and Iraq wars versus the China economic boom in the early 2000's. Because of this, these developments can't be fully assessed on the impact they actually caused solely. A way to solve this, is doing an extensive assessment on each event or development that occurs.

HUMAN COMPONENT

A problem throughout the whole thesis is the human aspect of it. The impact caused by a happening is much dependent on how it is perceived by the markets. If speculation controls the market, it becomes more complex to foresee the impact of new events and developments. This thesis was not able to eliminate the negative sides of this issue.

NEXT LEVEL INDICATORS

Some signals are identified, such as the start of an economic boom or a war, which could be broken down further. This would possibly reveal a next level of indicators. Therefore, a follow-up study would be recommended in the specific field of study. E.g. political

motivations leading up to a war or implementation of free market principles leading up to an economic boom. Other examples are the innovations in deep sea mining and recycling.

Other Commodities

The use of the proposed methodology and its indicator are not dependent on solely the copper market. A follow-up study on this methodology, in the context of other commodities, would reveal the applicability.

APPENDIX

APPENDIX ON CHAPTER 1

Table A1: In 1998 and 2010, the USGS has published a list with events, that had a significant effect on the copper price. This list is shown in this table, together with the time span in which the events occurred (Edelstein 1998, 2010).

	Start	End	Event
1	1961	1962	Record high production rates
2	1961	1962	Strong Consumption
3	1964	1966	Vietnam War begins (1964-1973)
4	1964	1966	Strong demand growth
5	1964	1966	Stockpile releases
6	1967	1968	Longest most severe strikes to date
7	1967	1968	Government stockpile releases, set aside programs, export controls and production stimulus programs initiated to meet defense needs
8	1967	1968	Formation of the Intergovernmental Council of Copper Exporting Countries (CIPEC)
9	1970	1973	Continuing high wartime demand
10	1970	1973	Easing of export controls and set-asides
11	1970	1973	Two-tier pricing generates Government concern
12	1970	1973	Price control limit rise
13	1970	1973	Nationalization of U.S.-owned Chilean properties
14	1970	1973	OPEC oil embargo begins
15	1974	1974	End of price controls
16	1974	1974	Strong demand
17	1974	1974	Last stockpile release
18	1974	1974	Fixed exchange rates abandoned
19	1975	1977	Demand drops precipitously due to recession
20	1975	1977	Copper inventories rise to record levels
21	1975	1977	Price Volatility
22	1978	1980	Record copper consumption and lower stock levels
23	1978	1980	Rising precious metal prices
24	1978	1980	5-month labour striks
25	1978	1980	Beginning of COMEX-based pricing
26	1982	1984	Recession
27	1982	1984	Inventory buildup
28	1982	1984	U.S. production sharply curtailed
29	1982	1984	Expansion of COMEX-based pricing
30	1985	1986	Draw down of high copper inventories

31	1985	1986	Cutback in capacity at U.S. mines
32	1985	1986	Cost-cutting and efficiency moves
33	1987	1989	Historically low inventories
34	1987	1989	Growing world consumption
35	1990	1992	Recession
36	1990	1992	Low global supply balances the recession
37	1990	1992	Dissolution of the Soviet Union
38	1990	1992	Political turmoil in Afric
39	1990	1992	Precarious supply/demand balance leads to price volatility
40	1993	1993	Stagnant world demand
41	1993	1993	Rising inventories
42	1993	1993	LME intervention in market causes sharp price drop
43	1994	1995	Strong global demand growth
44	1994	1995	Sharp inventory decline
45	1994	1995	LME opens U.S. warehouses
46	1996	1996	Sumitomo Corp. Reveals huge trading losses
47	1996	1996	Global inventory decline
48	1997	1999	Asian economic crises
49	1997	1999	Rapid expansion of global capacity combine to generate large global surplus
50	1999	2000	Asian demand growth
51	1999	2000	Production cutbacks reduced oversupply
52	2001	2002	Global recession
53	2001	2002	Reduced demand
54	2001	2002	Large inventory buildup
55	2001	2002	China displaced the U.S. as leading world consumer of refined copper
56	2004	2007	Explosive growth in China's demand
57	2004	2007	Production disruptions and delays in new capacity constrained supply
58	2004	2007	Global exchange inventories fell to minimal levels
59	2004	2007	Buoyed by investment interest
60	2008	2008	Global Economic Crisis
61	2009	2010	Extraordinary growth in China's apparent consumption
62	2009	2010	Continued supply constraints
63	2009	2010	Renewed interest in commodity investments

Table A2: The list of significant events is subdivided into categories. Those categories are determined in section 2.1.2. This tables shows all events and the corresponding category to which the events are assigned.

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	Categorie	Event
1	Supply	Record high production rates
2	Demand	Strong Consumption
3	War/Conflicts	Vietnam War begins (1964-1973)
4	Demand	Strong demand growth

5	Dependent	Stockpile releases
6	Special Event	Longest most severe strikes to date
7	Dependent	Government stockpile releases, set aside programs, export controls and production stimulus programs initiated to meet defense needs
8	Supplemental Information	Formation of the Intergovernmental Council of Copper Exporting Countries (CIPEC)
9	Dependent	Continuing high wartime demand
10	Dependent	Easing of export controls and set-asides
11	Dependent	Two-tier pricing generates Government concern
12	Dependent	Price control limit rise
13	Accessibility	Nationalization of U.S.-owned Chilean properties
14	Special Event	OPEC oil embargo begins
15	Dependent	End of price controls
16	Demand	Strong demand
17	Dependent	Last stockpile release
18	Dependent	Fixed exchange rates abandoned
19	Demand	Demand drops precipitously due to recession
20	Dependent	Copper inventories rise to record levels
21	Dependent	Price Volatility
22	Demand	Record copper consumption and lower stock levels
23	Dependent	Rising precious metal prices
24	Supplemental Information	5-month labour striks
25	Dependent	Beginning of COMEX-based pricing
26	Economic Crises	Recession
27	Dependent	Inventory buildup
28	Dependent	U.S. production sharply curtailed
29	Dependent	Expansion of COMEX-based pricing
30	Dependent	Draw down of high copper inventories
31	Dependent	Cutback in capacity at U.S. mines
32	Dependent	Cost-cutting and efficiency moves
33	Dependent	Historically low inventories
34	Demand	Growing world consumption
35	Supplemental Information	Recession
36	Supplemental Information	Low global supply balances the recession
37	War/Conflicts	Dissolution of the Soviet Union
38	War/Conflicts	Political turmoil in Afric
39	Dependent	Precarious supply/demand balance leads to price volatility
40	Supplemental Information	Stagnant world demand
41	Dependent	Rising inventories
42	Special Event	LME intervention in market causes sharp price drop
43	Demand	Strong global demand growth
44	Dependent	Sharp inventory decline
45	Dependent	LME opens U.S. warehouses

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46	Special Event	Sumitomo Corp. Reveals huge trading losses
47	Demand	Global inventory decline
48	Economic Crises	Asian economic crises
49	Supply	Rapid expansion of global capacity combine to generate large global surplus
50	Demand	Asian demand growth
51	Dependent	Production cutbacks reduced oversupply
52	Economic Crises	Global recession
53	Dependent	Reduced demand
54	Dependent	Large inventory buildup
55	Demand	China displaced the U.S. as leading world consumer of refined copper
56	Demand	Explosive growth in China's demand
57	Dependent	Production disruptions and delays in new capacity constrained supply
58	Dependent	Global exchange inventories fell to minimal levels
59	Dependent	Buoyed by investment interest
60	Economic Crises	Global Economic Crisis
61	Demand	Extraordinary growth in China's apparent consumption
62	Dependent	Continued supply constraints
63	Dependent	Renewed interest in commodity investments

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Appendix on Chapter 4

Cases

A case is used to bring the proposed method in extra perspective. The case will discuss the major events occurring in the early 70's. As can be seen in figure 2.17, those events caused a major peak and resulted in, when corrected by inflation, one of the historical highest price levels. The following three events played an important role:

1. US Involvement in the Vietnam War (1964-1973): The US involvement was a major event and happened over a long period for almost 10 years. The peak of the involvement was in 1968 and the US started to withdraw in 1969. The war caused a higher demand in copper due to use of it in bullets, fast replacement of equipment, maintenance and building infrastructure. The argument for this is made in section 7.6.1.1. The event was strong and long enough to raise the average copper price for almost 10 years (US Department of State, Offiee of the Historian 2013*a,b*).

2. Nationalization in Chile and Chilean Coup d'état (1969-1973): In the early 70's president Allende passed a law to nationalize the mines and other industries in Chile. It appeared to be working for Chile. However, rising wages produced a boom in consumerism and expensive products needed to be imported. Combined with a dropping price of Copper, Chile faced new kind of threats and could not meet its obligations any more. Financial crises became unrest and unrest resulted in a coup. During 1973 Augusto Pinochet took over presidency. The causality is made that the unrest and coup are the dominant causes for this peak in the copper price, this is explained in detail in section 7.5.1.1 (US Department of State, Offiee of the Historian 2013*a,b*).

3. Oil Embargo (1973-1974): As retaliation for US support for Israel during the Yom Kippur War, during the postwar negotiations, the Organization of Petroleum Exporting Countries imposed an embargo against the US. This resulted in extremely high oil prices and had an influence on the copper price as well. But at the time that oil started its rise from the base, copper was already at extremely high levels, due to the events in Chile. It is assumed that the spike is caused by the Oil Embargo. Due to increasing marginal costs, the price for copper continued to rise to extremely high price levels. The argument for this is made in section 7.2.2.1. (US Department of State, Offiee of the Historian 2013*a,b*).

The impact of all events can now, step by step, be calculated by using 5.3. The first is the oil embargo and for this it is assumed that the one year moving average is pushed up by the events in Chile and that the spike is pushed to extreme heights due to the embargo. By using the formula as defined earlier, Impact S can be calculated. In this case: $S_{OilEmbargo} = Low$. Figure A1 makes more clear on which area is focused.

Next is the impact of the Chilean events (figure A2). As stated, it is assumed that the one year moving average is pushed up by the events in Chile, and so this is the "real price" caused by it. If these events had not happened, the expectation is that the Vietnam War had defined the price. So instead of the one year moving average, the ten year moving average will be used as consensus. The result is $S_{ChileanEvents} = High$
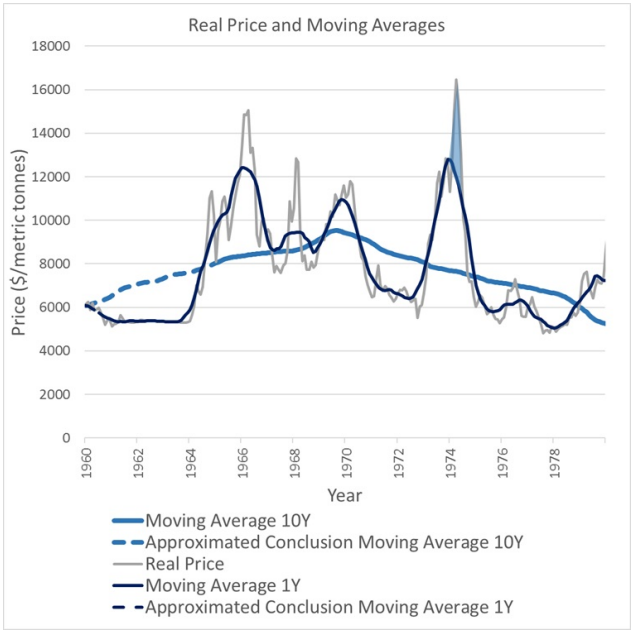
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Figure A1: The impact on the copper price caused by the oil embargo is marked.

For the last event, the "real price" is now defined by the Vietnam War and so the ten year moving average, because this line represents the long term events. For the consensus it is more complicated. Because there is not much to relate to, an alternative is made. In this specific case the starting point of the events impact range is used. And again, $S_{VietnamWar} = ExtremelyHigh$ and figure A3 give a view on the area which is calculated.
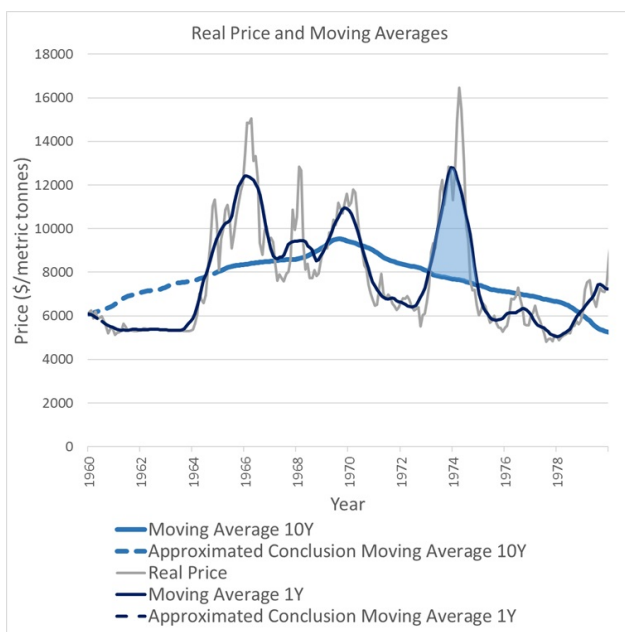
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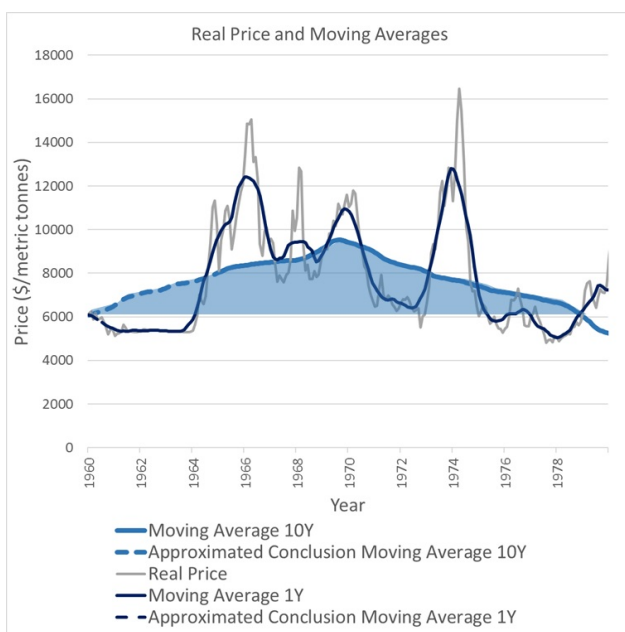Figure A2: The impact on the copper price caused by the events in Chile is marked.

Figure A3: The impact on the copper price caused by the Vietnam war is marked.

BIBLIOGRAPHY

ABN Amro (2014), 'Copper price as an economic indicator', `https://insights.abnamro.nl/en/2014/10/copper-price-economic-indicator/`. visited on 27-04-2016.

About Money (2016), 'How the dollar impacts commodity prices', `http://commodities.about.com/od/researchcommodities/a/How-The-Dollar-Impacts-Commodity-Prices.htm`. visited on 05-07-2016.

Anglo American (2016*a*), 'Annual report 2015', `http://www.angloamerican.com/~/media/Files/A/Anglo-American-PLC-V2/documents/aa-ar-15.pdf`. visited on 10-08-2016.

Anglo American (2016*b*), 'History', `http://www.angloamerican.com/about-us/history`. visited on 28-06-2016.

Anglo American (2016*c*), 'Strategic Focus on World-Class Assets and Sustainable Positive Free Cash Flow to Strengthen Balance Sheet - Creating the New Anglo American', `http://www.angloamerican.com/media/press-releases/2016/16-02-2016a`. visited on 28-06-2016.

Armed Conflict Location & Event Data Project (2016), 'Africa data', `http://www.acleddata.com/data/`. visited on 23-08-2016.

Barrick (2014), 'Barrick to Suspend Operations at Lumwana Following Passage of New Mining Royalty', `http://www.barrick.com/investors/news/news-details/2014/Barrick-to-Suspend-Operations-at-Lumwana-Following-Passage-of-New-Mining-Royalty/default.aspx`. visited on 09-06-2016.

BBC (2013), 'What happened to Japan's electronic giants?', `http://www.bbc.com/news/world-asia-21992700`. visited on 13-06-2016.

BHP Billiton (2015), 'BHP Billiton Copper - Strong fundamentals, unrivalled resource, world-class operations', `http://www.bhpbilliton.com/~/media/bhp/documents/investors/news/2015/151201_coppersitetourday1.pdf?la=en`. visited on 28-06-2016.

BHP Billiton (2016), 'BHP Billiton Chronology', `http://www.bhpbilliton.com/~/media/bhp/documents/aboutus/ourcompany/our-history/150702_ourhistory_shortbooklet.pdf?la=en` and `http://www.bhpbilliton.com/~/media/bhp/documents/aboutus/ourcompany/our-history/150731_ourhistory_escondida.pdf?la=en`. visited on 27-09-2016.

Bloomberg (2016), 'Here's how electric cars will cause the next oil crisis', http://www.bloomberg.com/features/2016-ev-oil-crisis/. visited on 23-08-2016.

Brealey, M. & Allen (2011*a*), *Principles of Corporate Finance*, McGraw-Hill/Irwin. pp.35-36.

Brealey, M. & Allen (2011*b*), *Principles of Corporate Finance*, McGraw-Hill/Irwin. p. 39.

Business Dictionary (2015), 'Economic boom', http://www.businessdictionary.com/definition/economic-boom.html. visited on 16-08-2016.

Business Dictionary (2016*a*), 'Development', http://www.businessdictionary.com/definition/development.html. visited on 29-08-2016.

Business Dictionary (2016*b*), 'Driver', http://www.businessdictionary.com/definition/driver.html. visited on 29-08-2016.

Business Dictionary (2016*c*), 'Indicator', http://www.businessdictionary.com/definition/indicator.html. visited on 29-08-2016.

C Tapia Cortez, S Saydam, J. C. & Sammut, C. (2015), 'Copper price uncertainties - chaos theory to manage risks in mining projects', *Third International Future Mining Conference, Sydney* pp. 261–272.

Cambridge Dictionary (2016), 'Signal', http://dictionary.cambridge.org/dictionary/english/signal. visited on -08-2016.

Castellanos, A. R. & Albizuri, N. S. M. (2011), 'The unpredictability of financial crises in a globalised world: Implications for public governance', *Globalisation, Governance and Ethics: New Managerial and Economic Insights* .

Center for Automotive Research (2006), 'Copper in end-of-life vehicle recycling', http://www.cargroup.org/?module=Publications&event=View&pubID=35. visited on 27-04-2016.

Chang, R., Hevia, C. & Loayza, N. (2010), Privatization and nationalization cycles, Technical report, National Bureau of Economic Research.

Chilean Copper Commission (2013, 2015), 'Chilean mining investments – project portfolio 2015 -2024, chilean mining investments – project portfolio 2013 -2021', http://www.cochilco.cl/english/research/research.asp. visited on 06-07-2016.

Chilean Copper Commission (2016), 'Rol del estado: nuevosescenarios y desafíos', http://www.cochilco.cl/archivos/presentaciones/20160429151046_Presentaci%C3%B3n%20Vice_SemPP_Expomin2016.pdf. visited on 07-07-2016.

CIA (2016*a*), 'The World Factbook - China', https://www.cia.gov/library/publications/the-world-factbook/geos/ch.html. visited on 21-06-2016.

CIA (2016*b*), 'The World Factbook - India', https://www.cia.gov/library/publications/the-world-factbook/geos/in.html. visited on 21-06-2016.

Closing the Loop (2016), 'What we do', http://www.closingtheloop.eu/. visited on 16-08-2016.

Cochilco (2014), 'Inventarios mundiales de cobre', http://www.cochilco.cl/estadisticas/inventarios.asp. visited on 11-07-2016.

Cochilco (2015), 'Producción cobre de mina por empresa', http://www.cochilco.cl/estadisticas/produccion.asp. visited on 15-08-2016.

CODELCO (2015), 'Mining in Chile: Future and Challenges', http://www.cochilco.cl/presentaciones/presentaciones.asp. visited on 13-07-2016.

CODELCO (2016), 'Historia', https://www.codelco.com/la_corporacion/historia.asp. visited on 06-06-2016.

Commodity Discovery Fund (2015), 'Urbanization is a lasting foundation for copper demand', http://www.cdfund.com/en/blog-eng/urbanization-is-a-lasting-foundation-for-copper-demand/. visited on 21-06-2016.

Congressional Research Service (2010), 'Costs of Major U.S. Wars', https://www.fas.org/sgp/crs/natsec/RS22926.pdf. visited on 22-06-2016.

Copper Alliance (2016*a*), 'Copper facts', http://copperalliance.eu/education-and-careers/copper-facts. visited on 12-07-2016.

Copper Alliance (2016*b*), 'Societal benefits landing page', http://copperalliance.org/societal-benefits-landing-page/energy-efficiency-4/. visited on 29-06-2016.

Copper Development Association Inc. (1998), 'Electric vehicles', http://www.copper.org/publications/newsletters/innovations/1998/02/ev_intro.html. visited on.

Copper Development Association Inc. (2010), 'Copper is an essential material for the future of the auto industry', http://www.copper.org/about/pressreleases/2010/pr2010_March_5.html. visited on 27-04-2016.

Copper Development Association Inc. (1999*a*), 'High tech house runs on copper', http://www.copper.org/publications/newsletters/innovations/1999/11/hightech.html. visited on 27-04-2016.

Copper Development Association Inc. (1999*b*), 'High tech house runs on copper', http://www.copper.org/publications/newsletters/innovations/1999/11/hightech.html. visited on 21-06-2016.

Copper Matters (2016), 'Copper in your car — even hybrids!', http://www.coppermatters.org/copper-powers-electric-cars/. visited on 27-04-2016.

Copper Matters (2016), 'Copper in technology — including your mobile phone!', http://www.coppermatters.org/copper-facts/. visited on 16-08-2016.

Council on Foreign Relations (2015), 'How the overseas contingency operations fund works—and why congress wants to make it bigger', http://blogs.cfr.org/davidson/2015/06/16/how-the-overseas-contingency-operations-fund-works-and-why-congress-wants-to-make-it-bigger/. visited on 22-06-2016.

Craig, J. (2001), 'Putting privatisation into practice: the case of zambia consolidated copper mines limited', *The Journal of Modern African Studies* **39**(03), 389–410.

Deloitte (2015), 'State of mining in africa', http://www2.deloitte.com/za/en/pages/energy-and-resources/articles/state-of-mining-in-africa-2015.html. visited on 09-06-2015.

Department of the Air Force (2005), 'Procurement program - procurement of ammunition', http://www.saffm.hq.af.mil/shared/media/document/AFD-070221-136.pdf. visited on 17-08-2016.

DNV GL (2016), 'Copper in comparison to aluminium as common material in conductors of lv and mv power cables; properties and related decision framwerok on how the conductor material is being selected', http://www.leonardo-energy.org/sites/leonardo-energy/files/documents-and-links/14-0601_dnv_gl_paper.pdf. visited on 30-06-2016.

ECB (2016), 'Long-term interest rate statistics for EU Member States', http://www.ecb.europa.eu/stats/money/long/html/index.en.html. visited on 04-07-2016.

ECO (2011), 'The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development. Workshops at the Twenty-Fifth AAAI Conference on Artificial Intelligence.', http://atlas.media.mit.edu/en/visualize/stacked/sitc/export/show/all/6821/1962.2013/. visited on -06-2016.

Economist (2011), 'The Big Mac index; Currency comparisons, to go', http://www.economist.com/blogs/dailychart/2011/07/big-mac-index. visited on 17-06-2016.

EDA (2016), 'Definitions', http://www.eda.europa.eu/info-hub/defence-data-portal/definitions. visited on 26-04-2016.

Edelstein, D. (1998), Metal Prices in the United States Through 1998, Technical report, USGS.

Edelstein, D. (2010), Metal Prices in the United States Through 2010, Technical report, USGS.

European Commission (2016), 'Climate strategies & targets', http://ec.europa.eu/clima/policies/strategies/index_en.htm. visited on 29-06-2016.

Federal Reserve (2015), 'Trade Weights as of October 26, 2015', http://www.federalreserve.gov/releases/H10/Weights/. visited on 23-08-2016.

Finance Yahoo (2016), 'How Freeport's Strategy Differs from Other Copper Producers', http://finance.yahoo.com/news/freeport-strategy-differs-other-copper-050408869.html. visited on 10-08-2016.

Financial Post (2010), 'He who pays the piper calls the mining tune', http://business.financialpost.com/fp-comment/he-who-pays-the-piper-calls-the-mining-tune. visited on 10-06-2016.

Financial Times (2011), 'Escondida strike to end', http://www.ft.com/cms/s/0/32234866-bf73-11e0-898c-00144feabdc0.html#axzz4HO3biMpY. visited on 15-08-2016.

Financial Times (2016), 'Commodities and brexit — 5 things to watch', http://www.ft.com/cms/s/2/9c3b7dde-387e-11e6-a780-b48ed7b6126f.html#axzz4I8fKb5Qe. visited on 23-08-2016.

Finnradiator (2016), 'Cuprobraze specialist in the radiator industry', http://www.finnradiator.com/. visited on 13-06-2016.

Freeport McMoRan (2015), 'Annual report summary', http://s2.q4cdn.com/089924811/files/doc_financials/annual/2015/10_k2015.pdf. visited on 27-06-2016.

Fund for Peace (2015), 'Fragile state index 2015', http://fsi.fundforpeace.org/rankings-2015. visited on 07-06-2016.

Geology.com (2016), 'The many uses of gold', http://geology.com/minerals/gold/uses-of-gold.shtml. visited on 12-08-2016.

GFMS (2013, 2014, 2015, 2016), GFMS Copper Survey, Technical report, GMFS.

Gilbert, C. L. (1989), 'The impact of exchange rates and developing country debt on commodity prices', *The Economic Journal* **99**(397), 773–784.

ICSG (2014), 'The world's 20 largest copper mines 2014', http://metals.about.com/od/Top-10-Producers/tp/The-Worlds-20-Largest-Copper-Mines-2014.htm. visited on 27-06-2016.

IEA (2015*a*), 'Energy Balances of OECD Countries', http://www.iea.org/publications/freepublications/publication/EnergyBalancesofOECDcountries2015editionexcerpt.pdf. visited on 29-06-2016.

IEA (2015*b*), 'Energy efficiency - market report 2015', https://www.iea.org/publications/freepublications/publication/MediumTermEnergyefficiencyMarketReport2015.pdf. visited on 29-06-2016.

Index Mundi (2016*a*), 'Commodity prices', http://www.indexmundi.com/commodities/. visited on 05-07-2016.

Index Mundi (2016*b*), 'Crude Oil (petroleum) Monthly Price - US Dollars per Barrel', http://www.indexmundi.com/commodities/?commodity=crude-oil$&$months=360. visited on 02-06-2016.

International Energy Agency (2015), 'Energy efficiency market report 2015', https://www.iea.org/publications/freepublications/publication/MediumTermEnergyefficiencyMarketReport2015.pdf. visited on 21-06-2016.

Investing News (2016), '10 top copper-producing companies', http://investingnews.com/daily/resource-investing/base-metals-investing/copper-investing/top-10-copper-producing-companies-2/. visited on 28-06-2016.

Investing.com (2016), 'US Dollar Index', http://www.investing.com/quotes/us-dollar-index-historical-data. visited on 05-07-2016.

Investopedia (2016), 'The basics of bollinger bands', http://www.investopedia.com/articles/technical/102201.asp. visited on 20-05-2016.

Investopedia (2015*a*), 'Boom', http://www.investopedia.com/terms/b/boom.asp. visited on 16-08-2016.

Investopedia (2015*b*), 'Why are the factors of production important to economic growth?', http://www.investopedia.com/ask/answers/040715/why-are-factors-production-important-economic-growth.asp. visited on 16-08-2016.

Investopedia (2016*a*), 'Discount rate', http://www.investopedia.com/terms/d/discountrate.asp. visited on 16-06-2016.

Investopedia (2016*b*), 'Financial crisis', http://www.investopedia.com/terms/f/financial-crisis.asp?ad=dirN&qo=investopediaSiteSearch&qsrc=0&o=40186.

Investopedia (2016*c*), 'Gross Domestic Product - GDP', http://www.investopedia.com/terms/g/gdp.asp. visited on 20-06-2016.

Investopedia (2016*d*), 'Inflation', http://www.investopedia.com/terms/i/inflation.asp. visited on 12-05-2016.

Investopedia (2016*e*), 'Marginal cost of production', http://www.investopedia.com/terms/m/marginalcostofproduction.asp. visited on 05-08-2016.

Investopedia (2016*f*), 'Mature economy', http://www.investopedia.com/terms/m/mature-economy.asp. visited on 21-06-2016.

Investopedia (2016*g*), 'Production cost', http://www.investopedia.com/terms/p/production-cost.asp. visited on 12-08-2016.

Investopedia (2016*h*), 'Purchasing Power Parity, PPP', http://www.investopedia.com/terms/p/ppp.asp, note=visited on 17-06-2016.

Investopedia (2016*i*), 'Trade-weighted dollar', http://www.investopedia.com/terms/t/trade-weighteddollar.asp. visited on 23-08-2016.

Investopedia (2016*j*), 'VIX - CBOE Volatility Index', http://www.investopedia.com/terms/v/vix.asp. visited on 27-05-2016.

Investopedia (2016*k*), 'Volatility', http://www.investopedia.com/terms/v/volatility.asp. visited on 27-05-2016.

Investopedia (2016*l*), 'What drives the price of gold?', http://www.investopedia.com/financial-edge/0311/what-drives-the-price-of-gold.aspx. visited on 04-07-2016.

J.H.L. Voncken, K. W. (2011), 'Economic minerals and rocks'. lectured at TU Delft, Faculty of Civil Engineering and Geosciencse, Department of Geoscience and Engineering.

JORC (2012), 'The jorc code 2012 edition', http://www.jorc.org/docs/JORC_code_2012.pdf. visited on 27-09-2016.

KALENGA, N. J. (2015), 'Development of the mining industry in congo: The copper industry in katanga, 1906-2012 [an abstract of entire text]'.

Kennecott (2014), 'Rio Tinto Kennecott marks one-year anniversary of Bingham Canyon Mine slide', http://www.kennecott.com/newsroom/copper-currents/rio-tinto-kennecott-marks-one-year-anniversary-bingham-canyon-mine-slide. visited on 13-07-2016.

KGHM (2015), 'New strategy of KGHM', http://kghm.com/en/new-strategy-kghm. visited on 28-06-2016.

Konkola Copper Mines plc (2016), 'History & milestones', http://kcm.co.zm/corporate-profile/company-overview/history-milestones/. visited on 10-08-2016.

LME (2015), 'Why are warehouses and brands important?', https://vimeo.com/147100093. visited on 14-06-2016.

Léniz, F. C. (2016), 'Histories of nationalization and privatization: the cases of the Chilean and Zambian Copper Industries'.

Lorenz, E. (1972), *Predictability: does the flap of a butterfly's wing in Brazil set off a tornado in Texas?*, na.

Macrotrends (2016*a*), 'Crude oil price history chart', http://www.macrotrends.net/1369/crude-oil-price-history-chart. visited on 11-02-2016.

Macrotrends (2016*b*), 'Gold prices - 100 year historical chart', http://www.macrotrends.net/1333/historical-gold-prices-100-year-chart. visited on 04-07-2016.

Macrotrends (2016*c*), 'U.S. Dollar Index Historical Chart', http://www.macrotrends.net/1329/us-dollar-index-historical-chart. visited on 28-09-2016.

Marglin, S. A. & Schor, J. B. (1990), *The golden age of capitalism: reinterpreting the post-war experience*, Oxford University Press.

McKinsey (2010), 'Whats Driving Africas Growth', http://www.mckinsey.com/global-themes/middle-east-and-africa/whats-driving-africas-growth. visited on 16-08-2016.

McKinsey (2016*a*), 'India's ascent: Five opportunities for growth and transformation', http://www.mckinsey.com/global-themes/employment-and-growth/indias-ascent-five-opportunities-for-growth-and-transformation. visited on 16-08-2016.

McKinsey (2016*b*), 'India's economy: Why the time for growth is now', http://www.mckinsey.com/global-themes/india/indias-economy-why-the-time-for-growth-is-now?cid=podcast-eml-alt-mgi-mgi-oth-1609. visited on 28-09-2016.

Meller, P. & Simpasa, A. M. (2011), 'Role of copper in the Chilean & Zambian economies: main economic and policy issues'.

Mikesell, R. F. (1979), *The World Copper Industry: Structure and Economic Analysis*, Resources for the Future. pp. 116-129.

MinEx Consulting (2010), '100 years of resource growth for copper - impact of costs, grade and technology', http://www.slideshare.net/RichardSchodde/growth-factors-for-copper-schodde-sme-mems-march-2010-finalslide13and23. visited on 28-04-2010.

Mining.com (2012), 'Chile's largest open pit copper mine goes underground', http://www.mining.com/chiles-largest-open-pit-copper-mine-starts-conversion-to-underground/. visited on 13-07-2016.

Mining.com (2015*a*), 'Anglo American to cut 85,000 jobs, dividend and assets in sweeping restructuring', http://www.mining.com/anglo-american-to-cut-85000-jobs-dividend-and-assets-in-sweeping-restructuring/. visited on 28-06-2016.

Mining.com (2015*b*), 'Most copper producers in Zambia losing money — Chamber of Mines', http://www.mining.com/most-copper-producers-in-zambia-losing-money-chamber-of-mines-23405/.

Mining.com (2015*c*), 'These 10 mines will set the copper price for the next decade', http://www.mining.com/these-10-mines-will-set-the-copper-price-for-the-next-decade/. visited on 27-06-2016.

Mining.com (2015*d*), 'Zambia to slash royalties, reinstate mining tax', http://www.mining.com/zambia-to-slash-royalties-reinstate-mining-tax/. visited on 09-06-2016.

Mining.com (2016), 'BHP hikes exploration spending, to focus mostly on copper, oil', http://www.mining.com/bhp-hikes-exploration-spending-to-focus-mostly-on-copper-oil/. visited on 28-06-2016.

Naidu, S. & Mbazima, D. (2008), 'China–african relations: A new impulse in a changing continental landscape', *Futures* **40**(8), 748–761.

Nasdaq (2016), 'The rise of electric vehicles by the numbers', http://www.nasdaq.com/article/the-rise-of-electric-vehicles-by-the-numbers-cm595564. visited on 10-08-2016.

National Institute on Standards and Technology (2016), 'Evaluating uncertainty components: Type a', http://physics.nist.gov/cuu/Uncertainty/typea.html. visited on 03-05-2016.

National Interest (2016), 'Will electric cars destabilize the world?', http://nationalinterest.org/feature/will-electric-cars-destabilize-the-world-16387. visited on 10-08-2016.

Nautilus Minerals (2016*a*), 'Fact sheet', http://www.nautilusminerals.com/IRM/Company/ShowPage.aspx?CategoryId=332&CPID=1792&EID=47251606. visited on 13-07-2016.

Nautilus Minerals (2016*b*), 'Nautilus Minerals', http://www.nautilusminerals.com/irm/content/default.aspx. visited on 13-07-2016.

Nautilus Minerals (2016*c*), 'Nautilus' Seafloor Production Tools arrive in Oman', http://www.nautilusminerals.com/irm/PDF/1731/NautilusSeafloorProductionToolsarriveinOman. visited on 16-08-2016.

Nelson, S. C. & Katzenstein, P. J. (2014), 'Uncertainty, risk, and the financial crisis of 2008', *International Organization* **68**(02), 361–392.

New York Times (2008), 'Vote in Alaska Puts Question: Gold or Fish?', http://www.nytimes.com/2008/08/23/us/23alaska.html?scp=3&sq=pebble%20mine&st=cse&_r=0. visited on 17-08-2016.

News.com.au (2016), 'Rio Tinto looks to copper future', http://www.news.com.au/finance/business/breaking-news/rio-tinto-looks-to-copper-future/news-story/b85454b730aa1c46075b30f02b45ba06. visited on 10-08-2016.

OECD (2014), 'Export restrictions in raw materials trade: Facts, fallacies and better practices', http://www.oecd.org/tad/benefitlib/export-restrictions-raw-materials.htm. visited on 10-06-2016.

OECD (2016), 'Members and partners', http://www.oecd.org/about/membersandpartners/. visited on 16-06-2016.

Office of Management and Budget (2015), 'Fiscal year 2015 - historical tables', https://www.whitehouse.gov/sites/default/files/omb/budget/fy2015/assets/hist.pdf. visited on 22-06-2016.

Oilprice.com (2014), 'The world's 10 biggest energy gluttons', http://oilprice.com/Energy/Energy-General/The-Worlds-10-Biggest-Energy-Gluttons.html. visited on 20-06-2016.

Park, S.-J. & Matunhire, I. (2011), 'Investigation of factors influencing the determination of discount rate in the economic evaluation of mineral development projects', *Journal of the Southern African Institute of Mining and Metallurgy* **111**(11), 773–780.

Perkins, P. E. (1997), *World Metal Markets: The United States Strategic Stockpile and Global Market Influence*, Greenwood Publishing Group.

Reuters (2016), 'BHP boosts exploration spend as focus narrows to oil, copper', http://www.reuters.com/article/us-australia-bhp-billiton-ltd-idUSKCN0ZD05A. visited on 10-08-2016.

Rio Tinto (2009), 'Outlook for commodity markets', http://www.riotinto.com/documents/Media-Speeches/MF_Global_Seminar_15_October_2009.PDF. visited on 07-09-2016.

Rio Tinto (2016*a*), 'BoAML Global Metals, Mining & Steel Conference 2016', www.riotinto.com/presentations. visited on 27-06-2016.

Rio Tinto (2016*b*), 'History', http://www.riotinto.com/aboutus/history-4705.aspx#tab_1873. visited on 28-06-2016.

Rio Tinto (2016*c*), 'Making mining history', http://m2m.riotinto.com/issue/4/article/making-mining-history. visited on 13-07-2016.

Rio Tinto (2016*d*), 'Rio Tinto Exploration', http://www.riotinto.com/documents/160627_Presentation_Citigroup_exploration_conference_Stephen_McIntosh.pdf. visited on 10-08-2016.

Rio Tinto (2016*e*), 'Taking the long view', http://m2m.riotinto.com/issue/6/article/taking-long-view. visited on 28-06-2016.

Roache, S. K. & Rossi, M. M. (2009), *The Effects of Economic Newson Commodity Prices: Is Gold Just Another Commodity?*, number 9-140, International Monetary Fund.

Rosen, S., Murphy, K. M. & Scheinkman, J. A. (1993), Cattle cycles, Technical report, National Bureau of Economic Research.

Siemens (2014), 'Aluminum versus copper conductors', `https://w3.siemens.com/powerdistribution/global/EN/tip/focus-markets/Documents/Siemens-Data-Center-Whitepaper-Aluminium-versus-Copper.pdf`. visited on 30-06-2016.

Sole, K. C. & Tinkler, O. (2014), 'Copper solvent extraction: Status, operating practices and challenges in the african copper belt', *Conference Paper, SME Conference, Phoenix AZ* .

Southern African Institute of Mining and Metallurgy (2012), 'The rise of resource nationalism: A resurgence of state control in an era of free markets or the legitimate search for a new equilibrium?', `http://www.saimm.co.za/Conferences/ResourceNationalism/ResourceNationalism-20120601.pdf`. visited on 10-06-2016.

State of Alaska (2016), 'Pebble project - current project description', `http://dnr.alaska.gov/mlw/mining/largemine/pebble//`. visited on 17-08-2016.

Statista (2016), 'Worldwide automobile production from 2000 to 2015 (in million vehicles)', `http://www.statista.com/statistics/262747/worldwide-automobile-production-since-2000/`. visited on 26-04-2016.

Svedberg, P. & Tilton, J. E. (2006), 'The real, real price of nonrenewable resources: copper 1870–2000', *World Development* **34**(3), 501–519.

The Economist (2016), 'Gold wins from brexit. but other commodities lose', `http://www.economist.com/news/business-and-finance/21701346-gold-wins-many-commodities-will-lose-ripple-effects`. visited on 23-08-2016.

The Guardian (2010), 'Chinese economic boom has been 30 years in the making', `https://www.theguardian.com/business/2010/aug/16/chinese-economic-boom`. visited on 16-08-2016.

The Guardian (2012), 'Inflation basket of goods 2012: full list of what's out and what's in', `http://www.theguardian.com/news/datablog/2012/mar/13/inflation-basket-goods-2012-full-list`. visited on 13-06-2016.

The Hague Centre for Strategic Studies (2012), 'Futures for copper', `http://www.hcss.nl/reports/futures-for-copper/97/`. visited on 22-08-2016.

The Independent Icelandic and Northern Energy Portal (2016), 'What Explains the High Energy Intensity in Iceland?', `https://askjaenergy.com/2013/04/08/what-explains-the-high-energy-intensity-in-iceland/`. visited on 20-06-2016.

The Wall Street Journal (2009), 'Copper miners go underground', `http://www.wsj.com/articles/SB10001424052748704201404574589941445376718`. visited on 13-07-2016.

The World Bank (2004, 2012, 2014*b*), 'GDP per capita, PPP (current international \$)', http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD. visited on 17-06-2016.

The World Bank (2004, 2012*b*), 'Energy use (kg of equivalent per capita)', http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE/countries/1W?display=graph. visited on 05-02-2016.

The World Bank (2012*a*), 'Acces to electricity (% of population)', http://data.worldbank.org/indicator/EG.ELC.ACCS.ZS/countries/1W?display=graph. visited on 05-02-2016.

The World Bank (2013), 'GINI index (World Bank estimate)', http://data.worldbank.org/indicator/SI.POV.GINI/countries/1W-PE?display=default. visited on 07-06-2016.

The World Bank (2014*a*), 'GDP per Capita (current US\$)', http://data.worldbank.org/indicator/NY.GDP.PCAP.CD. visited on 17-06-2016.

The World Bank (2014*c*), 'High-technology exports (http://data.worldbank.org/indicator/TX.VAL.TECH.MF.ZS. visited on 20-06-2016.

The World Bank (2014*d*), 'Manufacturing, value added (current LCU)', Manufacturing, valueadded(currentLCU). visited on 16-08-2016.

The World Bank (2014*e*), 'Military Expenditure (% of GDP)', http://data.worldbank.org/indicator/MS.MIL.XPND.GD.ZS. visited on 27-04-2016.

The World Bank (2014*f*), 'Population, total', http://data.worldbank.org/indicator/SP.POP.TOTL?display=graph. visited on 05-02-2016.

The World Bank (2014*g*), 'Urban population (% of total)', http://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS/countries/1W?display=graph. visited on 05-02-2016.

The World Bank (2016), 'What is an "international dolar"?', https://datahelpdesk.worldbank.org/knowledgebase/articles/114944-what-is-an-international-dollar. visited on 17-06-2016.

Thompson, M. (1993), *Base Metals Handbook*, Elsevier. pp. 3.1(22)-3.1(24).

Tilton, J. E. (2014), 'Cyclical and secular determinants of productivity in the copper, aluminum, iron ore, and coal industries', *Mineral Economics* **27**(1), 1–19.

Transparency International (2005), 'Corruption perceptions index 2005', http://www.transparency.org/research/cpi/cpi_2005/0/. visited on 06-06-2016.

Transparency International (2015), 'Corruption perceptions index 2015', http://www.transparency.org/cpi2015. visited on 06-06-2016.

US Department of State, Offiee of the Historian (2013*a*), 'Milestones: 1961-1968', https://history.state.gov/milestones/1961-1968. visited on 17-03-2016.

US Department of State, Offiee of the Historian (2013*b*), 'Milestones: 1969-1976', https://history.state.gov/milestones/1969-1976. visited on 17-03-2016.

US History (2016), 'Ronald Reagan's Military Buildup', http://www.u-s-history.com/pages/h1957.html. visited on 26-04-2016.

US Inflation Calculator (2016), 'Historical inflation rates: 1914-2016', http://www.usinflationcalculator.com/inflation/historical-inflation-rates/. visited on 28-01-2016.

USGS (2005), 'Porphyry copper deposits of the world: Database, map, and grade and tonnage models', http://pubs.usgs.gov/of/2005/1060/. visited on 08-08-2016.

USGS (2007), 'Sediment-hosted copper deposits of the world', http://mrdata.usgs.gov/sedcu/. visited on 08-08-2016.

USGS (2009), 'Copper, a metal for the ages', http://minerals.usgs.gov/minerals/pubs/commodity/copper/. visited on 01-06-2016.

USGS (2010*a*), 'Copper Recycling in the United States in 2004', http://pubs.usgs.gov/circ/circ1196x/pdf/circ1196X.pdf. visited on 12-07-2016.

USGS (2010*b*), 'Metal prices in the united states through 2010', http://pubs.usgs.gov/sir/2012/5188/. visited on 04-07-2016.

USGS (2016), 'Mineral commodity summary - all commodities', http://minerals.usgs.gov/minerals/pubs/mcs/2016/mcs2016.pdf. visited on 05-07-2016.

USGS Commodity Summaries (1996-2016), 'Mineral commodity summaries', http://minerals.usgs.gov/minerals/pubs/commodity/copper/. visited on 01-06-2016.

USGS Minerals Yearsbooks (1960-2013), 'Minerals yearbook', http://minerals.usgs.gov/minerals/pubs/usbmmyb.html, http://minerals.usgs.gov/minerals/pubs/commodity/copper/. visited on 01-06-2016.

VICE NEWS (2015), 'Canadian mining companies better beware, the liberals are coming for them', https://news.vice.com/article/canadian-mining-companies-better-beware-the-liberals-are-coming-for-them?utm_source=vicenewsfb4. visited on 10-06-2016.

Voncken, J. (2016), *The Rare Earth Elements*, 1 edn, Springer International Publishing. pp. 112-113.

Wills, B. & Atkinson, K. (1991), 'The development of minerals engineering in the 20th century', *Minerals Engineering* **4**(7), 643–652.

Wood Mackenzie, Bloomberg and AllianceBernstein (2015), 'Copper Prices and Marginal Production Costs', `https://blog.abglobal.com/post/en/2013/03/feared-copper-flood`. 12-04-2016.

Yahoo Finance (2016), 'Historical Prices S&P 500', `https://finance.yahoo.com/q/hp?s=%5EGSPC&a=00&b=3&c=1950&d=04&e=27&f=2016&g=m`.

YCharts.com (2016), 'Copper LME Settlement Price', `http://ycharts.com/indicators/copper_lme_settlement_price`. visited on 29-01-2016.