Bachelor thesis

Cross-hedging copper scrap:

an examination of the optimal hedge ratio and market price determinants

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Handed in on: **May 18, 2020**

Management Summary

Copper is a unique metal, which finds due to its particular characteristics a wide range of applications. There is a large demand for the material, which is only available in very limited amounts. The supplied quantities thereby not only depend on various mines all over the world but also on recycled copper scrap from scrap yards. Overall, this constellation creates an extensive global market with volatile price movements. In order to reduce price risk, copper scrap traders often engage in trading futures contracts at the London Metal Exchange. Their goal is to offset losses in their physical positions with price movements from opposed financial positions. The ratio between the two positions is called “hedge ratio”.

This research’s aim is to determine the optimal hedge ratio that a copper scrap trader should apply when hedging a physical position on the LME futures market. While in the industry the hedge ratio of 1.0 (in the research community often called “naïve hedge ratio”) is commonly applied, it is not given that the LME copper futures prices and copper scrap prices move exactly simultaneously. Therefore, the naïve hedge ratio can lead to remaining open positions and consequently also to unnecessary and undesired risk-taking. Also, other market price determinants of the copper scrap market are examined. The aim is to provide traders a deeper insight into the mechanics of the scrap markets. The focus is thereby mainly on the deductions for different scrap qualities, the LME warehouse stock and the LME copper basis.

The applied methods rely strongly on linear regression respectively the ordinary least square model. This research focuses on the European copper market and uses millberry and refinery material to represent different qualities of copper scrap. The data set used ranges from the end of 2011 until the beginning of 2020.

The findings show that over the last eight years a hedge ratio lower than 1.0 would have been more efficient when hedging on a horizon of three months. Concretely, while for millberry a hedge ratio of 0.95 would have been optimal, refinery material would have been hedged most effectively with a ratio of 0.88. Nevertheless, an out-of-sample test further outlines that such a stationary hedge ratio is not consistently outperforming the naïve hedge ratio. Further investigations point out that the hedge ratio in itself is subject to rather strong variations, which is why a dynamic hedge ratio might be the better choice compared to the stationary counterpart. A portfolio simulation with dynamic hedge ratios

and different window lengths shows a better overall performance and therefore supports this hypothesis.

In conclusion, this research suggests that trading firms can reduce the price volatility of their copper portfolios by adopting a dynamic hedge ratio instead of the commonly applied naïve hedge ratio.

Further, an analysis of the above-mentioned market price determinants shows that deductions for copper scrap materials have a tendency to move similarly. However, a relationship between the deductions and the LME warehouse stock data respectively the LME basis was not found.

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1 Introduction to the physical copper market

1.1 Copper

Although copper can often not be observed directly in the daily routine, today's modern life would not be possible without the uniquely orange metal. Thanks to its characteristics, it is used in many different ways in a wide range of industries. Especially due to its electric conductibility, it is often applied in cables, computers, cars or phones. Also electric power stations and high-voltage power supply systems rely on large amounts of the orange metal to bring power from A to B. But copper not only well conducts electricity, it is also very resistant to corrosion. For this reason, it can further be found in water- and heating-systems or as covering material on roofs. According to Copper Alliance, approximately 45% of today's copper is used in power generation and transmission, 20% in construction, 12.5% in electronic appliances and 12.5% in transport. The remaining 10% is used in other (non-electrical) applications (International Copper Association, 2017). In order to adapt the material's characteristics, in particular to make it harder, copper can be combined with other metals such as zinc or tin. The resulting alloys are called brass or bronze.

1.2 Supply

The wide applicability of copper creates a large demand, which is backed with supply from mines all over the world. The currently known copper reserves hidden in the earth are estimated to contain 830 million (metric) tonnes of copper (U.S. Geology Survey, 2019). If including the unknown copper resources, global reserves are estimated to include a total of 5'600 million tonnes (Johnson, Hammarstrom, Zientek, & Dicken, 2014). But mining is not the only way to gain usable copper. Also scrap yards buy used copper and bring it back into the cycle by selling it to smelters or refineries. Thanks to recycling, out of the 550 million tonnes of copper that were produced since 1900, approximately two-third are still in productive use today (Glöser, Soulier, & Tercero Espinoza, 2013).

While in 1980, global yearly market volume was approximately 9 million tonnes of copper, in 2018, this number had more than tripled to approximately 28 million tonnes. Of this amount, one third was not mined, but recycled (International Copper Association, 2019). It is important to mention, that copper is one of the few materials that is 100%

recyclable. This means it can be retreated and reused as many times as desired, without any loss in neither its characteristics nor its performance (Aurubis, 2016). For this reason, it is expected that recycling copper will play a more and more important role in the copper supply of the future.

1.3 Demand

Global demand for copper is heavily concentrated in industrialized countries. Especially Asia plays nowadays an important role. China alone covered nearly 50% of the demand for refined copper in 2017. Other Asian countries, including India, covered an additional 20%. Europe and North America covered 18% and 12% (International Copper Study Group (ICSG), 2017).

With a demand of over 4.1 million tonnes of copper in Europe, but a production of only 3.8 million tonnes, Europe must import copper to fully cover its demand (International Copper Study Group (ICSG), 2017).

1.4 Materials and qualities

Copper as a commodity can be supplied in many different forms, whereby it is common to distinguish between primary and secondary raw materials. Primary raw materials contain copper ore and concentrates, while secondary materials contain recycling materials respectively copper scrap.

1.4.1 Primary raw materials

Copper ore (ca. 0.5 -4% copper content) is usually processed directly near the mines. The resulting copper concentrates (ca. 30% copper content) is then sold to smelters. (Aurubis, 2017)

Of the approximately 19 million tonnes of copper concentrate, that was supplied by mines all over the world in 2018, approximately 40% was produced by Chile and Peru. After them follows China with 8% and the USA with 6%. Other important producing countries are DR Congo, Australia, Zambia and Mexico. They all cover between 3 -5 % of the total production (Statista, 2020). The list of copper exporting countries is also lead by Chile and Peru, which cover with 29.5% and 20.1% nearly 50% of the total export market. Other important exporting countries are Australia, Indonesia, Canada and Brazil, which all cover an export market share of approximately 4 – 7% (International Copper Study Group (ICSG), 2017). China, USA and some of the smaller producing countries do not appear on the list of exporters since they use up more copper than they can produce themselves.

1.4.2 Copper recycling material (copper scrap)

Recycled copper has established itself as an important alternative to concentrates for the smelters. There is a wide range of materials available on the recycling market, whose actual copper content can reach from very low (below 20%) to very high (up to 99.9%). Depending on the copper content, a variety of different processes need to be applied to purify the copper.

Since individual recycling materials do often not only contain copper but are mixed or alloyed with other metals such as tin, zinc, silver or gold, the prices for certain copper scrap qualities are not solely determined by the copper price. This research, however, focuses on materials that do not contain other metals or, if they should contain other metals, they do not influence the price and can therefore be neglected or considered as worthless. Two materials will be examined in particular: “refinery material” and “millberry”. In this research, the prices of those two materials are used as a representation for copper scrap with high copper content.

1.4.2.1 Refinery material

Copper refinery material is a common expression to describe a particular quality of copper scrap. It mainly consists out of old, used and often oxidized pieces of copper such as rainwater guttering or roofing. Also old used copper sheets and pipes can be classified as refinery material. The sheets must thereby be at least 0.15 mm thick. It is unavoidable that leftovers of lead, tar or other substances impure the material, which is why its actual copper content is at around 95% (Thommen, 2017).

According to the norm DIN EN-12861:1999, refinery material is classified under the code S-Cu-9. The norm stipulates, that the individual pieces must be at least 30 mm wide in at least one direction (DIN Deutsches Institut für Normung e.V., 2000). Furthermore, it stipulates the following limits:

Material description:		Composition in %				
Code	Number	Element:	Copper (Cu)	Aluminium (Al)	Iron (Fe)	Nickel (Ni)
S-Cu-9	CS54B	Min: Max:	96* -	- 0.2	- 0.5	- 0.2
		Element:	Lead (Pb)	Tin (Sn)	Zinc (Zn)	Other metals in total
		Min: Max:	- 1,5	- 0.5	- 1.5	- 0.1
*Including Silver (Ag) up to 0.015% and Oxygen (O) up to 0.06%.						

(DIN Deutsches Institut für Normung e.V., 2000)

In the industry, the above stated definition is used to determine the top quality of refinery material. However, the actual copper content can also be lower, while all the other limits still apply. In other terms, while 96% copper content defines the highest quality level, only 80% copper content is required to classify the material as refinery material. Since prices are defined according to the actual copper content, different prices apply for different levels. The basis for the price determination is thereby 95%, from which further deduction or premiums are calculated for lower or higher copper content levels (Thommen, 2017). In this study, it is always assumed that refinery material contains 95% copper and consequently, no further deductions or premiums apply. The prices used will also always be calculated for refinery material with 95% copper content.

1.4.2.2 Millberry

Millberry is with a purity of 99.9% copper amongst the cleanest of all types of copper scrap. It mainly consists of clean, unburned, not alloyed copper wires (Thommen, 2017). According to the norm DIN EN 12861: 1999, where it is classified under the code S-Cu-1, the wires must be at least 1 mm thick (DIN Deutsches Institut für Normung e.V., 2000). Further, the following limits apply:

Material description:		Composition in %				
Code	Number	Element:	Copper (Cu)	Bismuth (Bi)	Phosphor (P)	Lead (Pb)
S-Cu-1	CS026A	Min: Max:	99.90* -	- 0.0005	- 0.001	- 0.005
*Including silver (Ag) up to 0.015%. All other elements cannot be higher than 0.002%						

(DIN Deutsches Institut für Normung e.V., 2000)

1.5 Supply chain

Copper must go a long way from the mine until it is ready to be used in a cable or a computer. In order to facilitate this research, the supply chain between the mine and the end-product manufacturer will be split into three main steps. Smelting, refining and manufacturing of semi-finished products.

1.5.1 Smelting

Smelting refers to extracting copper from copper ore, concentrates and low-grade recycling materials. This is usually done in different types of furnaces, where the material is heated up to high temperatures and then separated in its different elements. Depending on the copper content of the material, different steps with different furnaces must be applied. The resulting copper is called anode copper and has a purity of approximately 96% copper (Montanwerke Brixlegg, 2019).

1.5.2 Refining

The refining process refers to purifying anode copper. It is heated up and cast into anodes, which are then hung into a bath filled with a sulfuric acid solution of copper sulphate. By putting this bath under electric current, an electromechanical process takes place that purifies the copper. The resulting plates are called cathodes, which have a copper content of 99.99%. This is one of the purest forms of industrial copper that is available on the market (Montanwerke Brixlegg, 2019).

1.5.3 Manufacturing

With its high purity, cathodes are the preferred raw product for foundries, mills and other semi-finished product producers (hereinafter called manufacturers). Manufacturers produce raw products in standardized forms such as rods, billets, pipes or cakes. These products are then ready to be used in the production of finished products like cables or computers (Montanwerke Brixlegg, 2019).

1.5.4 Buyers of copper scrap

It is important to note that each participant in the supply chain also buys copper scrap with copper contents that suit his process. Smelters buy copper concentrates and copper scrap with lower than 96% copper content (such as refinery material) to produce anode copper. Refineries buy anode copper and copper scrap with higher than 96% copper and produce cathodes. Foundries, mills and other manufacturers buy cathodes and very high grade of copper scrap (min. 99.9% copper) and produce semi-finished products. It is typical for refineries as well as manufacturers to buy millberry in order to use it as a complement in their production processes (Thommen, 2017).

1.6 Dynamics of supply and demand

Mining copper ore and processing it up to a point, where it is ready to be applied in a car or a computer is a very infrastructure- and time-intensive process. Opening new mines or building new smelters and refining plants is costly and time-consuming. This leads to the facts that the supplied amounts are rather constant and only change slowly. The demand side, however, depends largely on the global economy (demand for consumer goods, construction industry, car industry, etc) that changes rapidly in today’s world. Consequently, the volatile demand and the sluggish supply do often not match with each other. Further, copper is a base element with unique characteristics. This makes it difficult to substitute it with another metal. The result of these circumstances is a very price inelastic market with large price volatilities (Bell, 2019).

These price volatilities pose a problem for any participant in the market that relies on long-term investments and price calculations over longer time-periods. A smelter, for example, needs to know to what price he can sell his anode copper in order to estimate to what price he can buy concentrates. A trading company, that buys concentrates in Chile and sells it later in Europe, needs to rely on a fix selling price in the future in order to estimate its buying price today.

In order to provide a solution to these price volatilities and absorb mismatches between supply and demand, copper futures exchanges have been created. What a copper futures exchange is and how its mechanisms work will be explained in the next section.

2 Introduction to the copper futures market

2.1 London Metal Exchange (LME)

One large exchange market for copper futures is provided by The London Metal Exchange (LME). There are also other exchanges such as the COMEX in Chicago or the SHFE in Shanghai. However, since all prices used in this research are LME prices, only the LME will be covered in this paper.

The LME is a company that provides a marketplace for many different metals, one of which is copper. In its fundamentals, the LME provides a marketplace where refineries can sell copper cathodes to manufacturers. Thereby, the refinery and the manufacturer must mutually agree on a fixed price and fixed delivery date in the future.

In concrete terms, on one side, a refinery (seller) might wish to sell 25 tonnes of cathodes in three months (calculated from today) at a given price. On the other side, a manufacturer (buyer) might wish to buy 25 tonnes of cathodes in three months at the same price. If they both go to the LME and state their intentions, the LME matches them together and creates a contract between them. The refinery will have to deliver the cathodes on the agreed date and the manufacturer will have to pay the agreed price on the same date. Such a contract is called "futures contract" or short a "futures". Entering such a contract as a buyer is referred to as "buying a futures contract". If such a contract is entered as a seller, it is called "selling a futures contract". This, however, is simply terminology, since the entering party in its fundamental does always only promise to buy or sell the underlying copper. The actual exchange of the money and the copper will be executed at the end of the contract at the delivery date.

2.2 Specifications of a copper futures

An important aspect of such a futures contract are the specifications. Since the LME wants to match buyers and sellers as efficiently as possible, the futures contracts are standardised to a high degree. They always contain one "lot" of copper cathodes, which is the equivalent to 25 tonnes (+/-2%). The cathodes themselves need to be classified as "Grade A", which is only given when they fulfil a narrow set of requirements according to one of the following standards: "BS EN 1978:1998 - Cu-CATH-1", "GB/T 467-2010 - Cu-CATH-1" or "ASTM B115-10 - cathode Grade 1" (The London Metal Exchange, 2020). Buyer and seller can only agree on this contract specifications, changes or other specifications are not possible. Also, the date when the cathodes are exchanged against the payment (officially called “settlement” date or “delivery” date) is unchangeable, once the futures contract has been entered. It is always calculated by using the date when the futures contract is entered, plus the agreed delivery delay (e.g. in three months). Therefore, the delivery date is usually indicated in periods of time, rather than in exact dates. The delivery point for the seller, respectively the pickup point for the buyer is always at one of the warehouses of the LME (The London Metal Exchange, 2018).

2.3 Warehouses

The LME licences and monitors 550 warehouses in 34 locations all over the globe (The London Metal Exchange, 2018). In order to be able to fulfil a contract, the seller must deliver the cathodes to one of the warehouses any time before the settlement date of his futures contract. In exchange, he receives a warrant, which entitles him to one lot of cathodes in the LME warehouse. When his futures contract reaches the settlement date, he will transfer the warrant to the buyer in exchange of the payment. Having received the warrant, the buyer is now entitled to one lot of copper and can pick up the cathodes at the LME warehouse.

One important aspect to note is, that since the holder of the warrant is always also the owner of the copper cathodes in the warehouse, the holder of the warrant is obliged to pay storage fees to the warehouse.

2.4 Price discovery

Since the LME is an open market, the prices the futures contracts are agreed on, are determined by the classical market mechanism of supply and demand. This means for every futures contract, one party (either buyer or seller) must propose a certain price and the other party has to agree on that price. Naturally, a seller that sells his copper in three months will propose a different price than a seller that wants to sell copper in one month, since higher storage costs or interest rates must be considered. Therefore, every delivery date must be considered as a separate market. Consequently, there is not only one price for copper cathodes but many prices according to different delivery dates. There is, for example, a price for copper delivered in 2 days (shortest delay possible; this price is also referred to as “Cash” or “spot” price) or a price for copper delivered in one month, two months or three months. As mentioned before, the dates, when the warrant has to be delivered and the payment is executed, are also called settlement dates.

From dates between “delivery in two days” and “delivery in three months” the LME provides a market for every day. After that, only weekly markets are provided. After six months the LME only provides monthly markets (For weekly markets, the exact settlement day is always Wednesday, for monthly markets always the third Wednesday) (The London Metal Exchange, 2018). The LME ensures that the dates are correctly adjusted on the contracts. So, what is the 10-days contracts today, will be the 9-days contract tomorrow and the 8-days contract in two days. Then, 8 days later, the contract will reach settlement and expire. The exchange between the warrant and the payment will be executed.

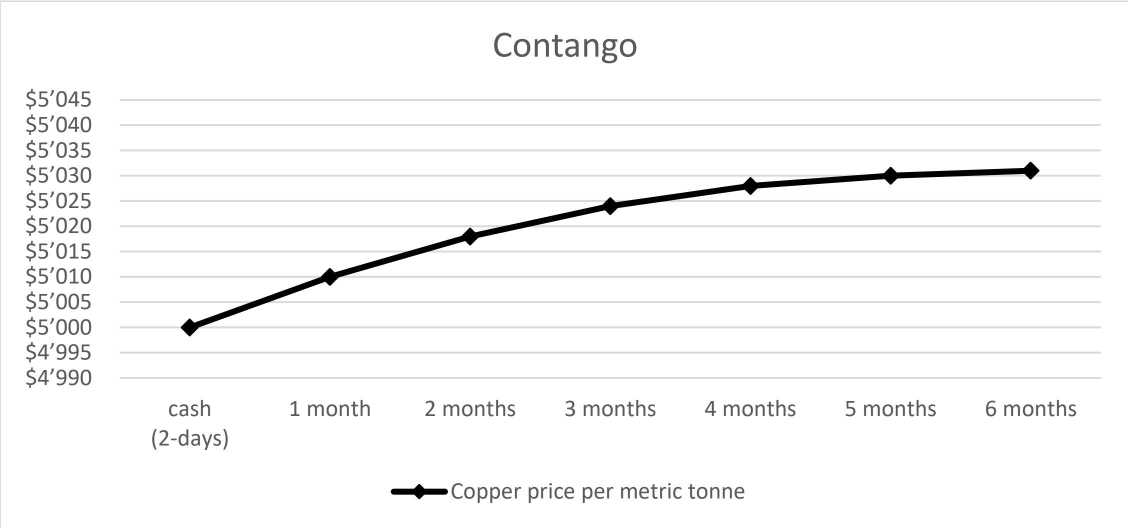
It is fundamental to realize that market participants can decide on which day in the future they want to deliver or take delivery by deciding on which market they want to buy or sell. However, they cannot decide where the physical cathodes will have to be picked up. The releasing warehouse will be determined randomly by the LME. This mechanism ensures, that the prices buyer and sellers determine on the LME do not represent a price that is tied to a certain delivery point, but a globally valid price (The London Metal Exchange, 2018).

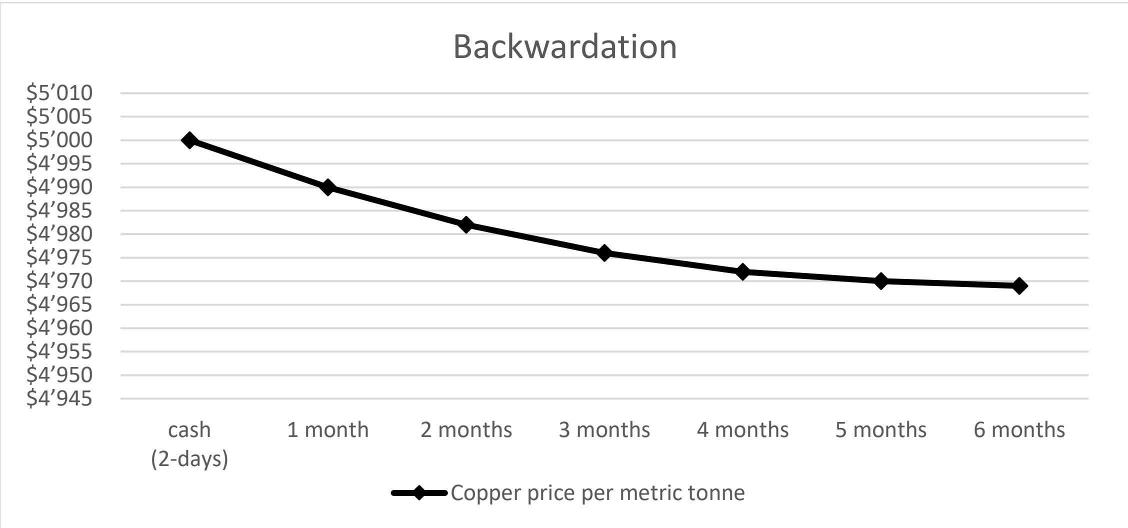
2.5 Contango and Backwardation

As already mentioned above, it is natural that the price for cathodes delivered in three months is higher than the price for cathodes delivered in one month. This is due to the fact that a producer that sells in three months will have to pay for longer storage times than one that sells in one month. Consequently, the producer will add up his additional storage costs to his expected selling price. Also, his money will be tied up in the cathodes for a longer time period, which eliminates the possibility to receive interest on the money. This overall market situation is called contango. Contango is the fact, that copper delivered in longer time periods from today is more expensive than copper delivered in shorter time periods from today. This situation is intuitively logical, due to storage cost and interest.

However, the overall market does not always have to be in contango. Since the price for every delivery date is determined on an individual market, the price for cathodes delivered in three months can also be lower than the price for cathodes delivered in one month. If this is the case, the overall market is considered to be in backwardation. Although this situation might seem counterintuitive, this can occur when market participant expect that it will be cheaper to buy cathodes in three months, rather than in one month. The reason for this could be a very short-term shortage or an expected oversupply in the future.

The two following graphs show the two concepts of contango and backwardation in a simplified hypothetical price situation:





2.6 Basis

The difference between the price for delivery in two days (cash-price) and the price for delivery in three months (or any other future delivery date) is called basis. If the basis is negative, the market is in contango (futures price is higher than cash price) and if the basis is positive, the market is in backwardation (future price is lower than cash price). If the future price rises with respect to the cash price, the basis becomes more negative. This is called weakening or also widening of the basis. If the opposite takes place, the basis is strengthening or narrowing (Dhuyvetter, 1992). If both prices change simultaneously in the same direction, the basis does not change since the difference between the two remains constant.

2.7 The LME official price

Even if the LME offers markets for many different delivery dates, two delivery dates play a particularly important role: the “cash”-contract (delivery-date in two days) and the three-months-contract (delivery date in three months). Although these contracts are also traded during the normal trading hours of the LME, four times a day they are additionally negotiated in a traditional open-outcry trading floor for five minutes. These sessions are called “Ring” or “Ring-Trading”. The prices that are determined in these rings will often be used as a reference price in the physical copper industry outside the LME for physical copper trading. The most important reference price is discovered in the second morning session. It is also called the “Official Price” and the most used reference price in the copper industry (The London Metal Exchange, 2018).

2.8 Reference price for physical markets outside the LME

2.8.1 Reference price for cathodes outside the LME

Even though refineries can bring their cathodes to an LME warehouse and sell the warrants that they receive over LME futures contracts, they are not obliged to do so. They can also circumvent the LME by contacting the manufacturers and selling the cathodes directly to them. If this is the case, they will usually agree on the LME official price respectively use it as a reference.

This agreement is based on the no-arbitrage-principle. The seller (refinery) would not agree on prices lower than the LME official price since he would otherwise prefer to sell his cathodes over the LME instead of directly to the manufacturers. The manufacturer, on the other side, will not agree on prices higher than the LME official price, since he would otherwise prefer to buy the cathodes over the LME instead of directly at the refinery. Therefore, buyer and seller will mutually agree on the official price when trading directly.

In other terms, since refineries and manufacturers always have the alternative to buy or sell cathodes on the LME, the price determined there will also always be the price that is valid for the physical cathode market outside the LME. This mechanism ensures that LME prices and the price paid on the physical market cannot diverge from each other (The London Metal Exchange, 2018).

2.8.2 Reference price for other copper materials

Since refineries use the LME prices to sell their cathodes, they will also use the LME prices to calculate their buying prices for raw materials. Its suppliers, in turn, will do the same. This creates a chain, which makes the entire supply chain dependent on the LME price. For example, a refinery knows it sells cathodes according to the LME price. It therefore buys anode copper for the LME price minus its processing costs. The smelter, who sells anode copper at that price, will then make an additional deduction for his smelting costs to estimate the buying prices for copper concentrates. The same is true in the other direction of the supply chain. Manufacturers buy cathodes at the LME price and sell their semi-fabricated products at the LME price plus a premium. The premium is thereby set to cover their manufacturing costs.

In conclusion, copper materials such as concentrates or copper scrap, that are eventually processed to cathodes, are traded at the LME price minus a deduction. Semi-fabricated copper products such as rods or pipes, that are produced out of cathodes will be traded at the LME price plus a premium. The cathodes themselves, being the product represented by the LME price, are traded at the LME price directly.

According to this mechanism, the prices for copper materials such as copper scrap, concentrates or semi-fabricated products are either lower or higher than the LME price. However, since they are all based on the LME price, they move simultaneously. If the LME price rises, the copper scrap price will also rise. If the LME price falls, the scrap price also falls. The differences between the prices thereby remains constant, given that the deductions and premiums that are applied also remain constant.

2.8.3 Price on payable copper content

At this point, it is important to mention that prices for copper materials are usually applied on the actual content of copper, rather than the amount of material delivered. For example, if a trading firm sells 100 tonnes of copper refinery material with 95% copper content, it will be paid 95 tonnes of copper content times the LME price minus the deduction. The remaining five tonnes will not be paid at all.

total price for 100 tonnes refinery material (95%Cu) = 95 tonnes*(LME price –deduction)

The 95 tonnes are called “payable copper content”. For millberry, the payable copper content is at 100%, since it already is 99.9% pure copper. The 0.01% impurity is usually neglected.

total price for 100 tonnes millberry (99.9% Cu) = 100 tonnes * (LME price -deduction)

For each quality of copper scrap, the deduction is set at a different level.

2.9 Transfer of price risk

Although supply chain participants base their buying and selling prices on the LME price, they can still be exposed to considerable price changes. Since buying and selling does not take place at the same moment, the LME price can rise or fall in between. This creates risk. How the LME allows avoiding that will be explained with the following paragraphs.

As explained before, when refineries and manufacturers trade over LME futures contracts rather than directly, they trade a given amount of copper cathodes on an agreed delivery date in the future. On this delivery or settlement date, the refinery must hand over a warrant and the manufacturer must execute the payment. In order to have a warrant to hand over, the refinery must deliver cathodes to an LME warehouse before the settlement is due. The refinery is free in deciding how much in advance it wants to deliver the cathodes. He can do so already before he even entered the futures contract or also just before the settlement is due.

2.9.1 Closing of contracts

If a refinery did not deliver the cathodes on time to the warehouse, it will not have a warrant at hand and would therefore be unable to fulfil its contract. In such a situation, the refinery must close its future contract with another futures contract. How this mechanism works is best outlined in an example.

A refinery (here called refinery “A”) sells a warrant to a manufacturer over a futures contract. Before settlement, the refinery realizes that it will not be able to deliver the cathodes on time, respectively will not have a warrant to fulfil the contract at settlement. To avoid this, refinery A will enter a second futures contract and buy a warrant from another refinery “B”. Refinery A will thereby make sure, that the settlement dates of his selling contract and the settlement date of his buying contract are the same. That way, on settlement date, refinery B will hand over the warrant to refinery A and refinery A can, as originally promised, hand it further on to the manufacturer.

In this example, refinery A sold a futures contract with a given settlement date and later bought a futures contract with the same settlement date. When the LME realizes, that the two settlement dates match, it will automatically exclude refinery A from its obligation to hand over the warrant by connecting the two contracts together. This means refinery B will hand over the warrant directly to the manufacturer. In consequence, there will be no physical obligation left for refinery A. A has “closed its position”.

The mechanism that a selling contract can be cleared with a buying contract and vice versa is referred to as “closing a position” and an automatically executed service of the LME. The only requirement is that both contracts have the same delivery date and are held by the same party.

It is important to note that not both contracts must be agreed at the same price. Although it is the same product and the same delivery date, during the time between entering the first contract and entering the second contract the market price might have changed. This can lead either to a profit or to a loss for the party that closed the position (here refinery A). It is further important to realize, that in this scenario, “A” never actually had to do any physical movements of cathodes. “A” promised to sell cathodes to one party and bought cathodes from another party. These two parties will then take care of the deliveries themselves, excluding “A” from any physical obligations.

Nevertheless, “A” was subject to price risk, since its promise to sell did not come at the same price as its promise to buy. In comparison, refinery B and the manufacturer both received the prices that they have agreed upon. In other words, the price risk that refinery B and the manufacturer would have had without the LME was transferred to refinery A, since A essentially pays (or receives) the difference between the two agreed prices.

2.10 Other Participants

The fact, that contracts can be entered and closed again without having any obligations to actually deliver or take delivery of physical copper opens the market for many other participants who do not own physical assets. Such participants specifically seek to profit from price movements, but do not own any warehouses or copper processing plants. In fact, refinery A in the above example would in reality not be a refinery, but rather a bank or investment fund who seeks price risk for its portfolio. Such participants know from the beginning on that they will be able to close their position and therefore also be able to avoid physical delivery.

Market participants without physical assets can be separated into two categories: speculators and hedgers.

2.11 Speculators

Speculators are market participants who enter futures contracts and close them again before delivery with the aim to profit from price changes. When a speculator expects prices to rise in the future, he will promise to buy copper with delivery in the future. He will then wait until prices have risen and then close his position by promising to sell copper on the same delivery date with the new (now higher) price. The LME connects the two contracts that he has entered, and the speculator will be free from physical obligations. The difference between the price he promised to buy at and the price he promised to sell at is his profit. In this scenario, the speculator bought first and sold later. This is called, “having a long position” and used to speculate on rising prices.

When the speculator expects prices to fall, he will promise to sell at a given date in the future and later, he will promise to buy at the new (now lower) price and thereby close his position. Again, the difference between selling and buying price is the speculator’s profit. In this scenario, the speculator sold before he bought. This is called “having a short position” and used to speculate on falling prices.

In both scenarios, it is important that the speculator always agrees in both contracts on the same delivery date, otherwise, the LME is unable to match the two contracts together and physical delivery of the two contracts will take place. Also, the speculator must make sure that he chooses in the first contract a delivery date that is far enough in the future, so that he has enough time to close the position with the opposing contract. Should he be unable to close his position or simply forget to do so, his counterparty will expect him to deliver or to be delivered with cathodes. Speculators are often banks or investment funds, which is why a physical delivery can be a problem.

Speculators are an important element of the LME and also for the entire copper market. By seeking to profit from price movements, they assume the price risk that other market participants try to avoid. Such market participants are called hedgers.

2.12 Hedgers

Hedgers are market participants who are by the nature of their business exposed to price risk and wish to pass on this risk to speculators. Typical examples for speculators are refineries and manufacturers, who need to find buyers respectively sellers already today, for products they want to sell or buy in the future. A refinery, for example, wants to know for what price it can sell cathodes in the future, in order to estimate the buying price for anode copper today. The refinery will therefore promise to sell at a certain price in the future at the LME and will have a reliable price to calculate with when buying the required raw materials. If at settlement date the actual spot price for buying and selling cathodes is much lower than the price it agreed on, this does not affect the refinery since it has already agreed on a fix selling price in advance. It is "hedged". However, if the price is much higher than the price it has agreed on, it will not be able to profit from the higher price either.

But hedgers are not only refineries and manufacturers. Since the prices for copper materials at any point in the supply chain depend on and move simultaneously to the LME price, any participant in the copper supply chain can hedge price risk by using LME futures contracts. This could be smelters, mines or traders of copper concentrates and copper scrap.

A concrete example is a copper scrap trader, that buys 26.31 tonnes of refinery material with 95% copper content (which results in 25 tonnes payable copper content) from a scrap yard and plans to sell it three months later to a smelter. The buying price will be determined by the LME price minus a deduction and later, the selling price will also be the LME-price minus a smaller deduction. Since between the purchase and the sale the LME-price can change, the scrap trader is subject to price risk. (Also on the physical market, such a situation can be considered as having a "long position", since the trading company buys copper scrap first and sells it later).

In order to pass on the price risk, the scrap trader will (simultaneously to his scrap purchase) promise to sell 25 tonnes of cathodes with a delivery date in three months on the LME. In other words, he enters a short position. Having bought at the physical market (long position) and sold on the LME exchange (short position), the two positions of the scrap trader cancel each other out and the overall position is considered to be neutral.

Three months later, the scrap trader will sell the 26.31 tonnes of refinery material to a smelter at the LME price minus the deduction. At the same time, it will buy a futures contract on the LME, with which he wants to closes his position shortly before settlement.

If during these three months, prices have fallen, the company will have made a loss by buying refinery material at high prices and selling it at low prices. However, the company will have made a gain on the futures contracts by promising to sell at a high price and later promising to buy at a low price. The loss on the refinery material will then be offset with the gain on the LME futures contracts. The same would be true if prices had risen. The gain that the scrap trader would have made by buying refinery material at low prices and selling it later at high prices would be offset with the loss made by promising to sell at low prices first and promising to buy at high prices later. Since gains and losses always offset each other, the company is hedged respectively not subject to price risk anymore.

The difference in the deductions that the trading firm applies when buying and selling the physical refinery material will eventually be the gross profit for the scrap trader.

Here, also the scrap trader makes use of the possibility to participate in the LME futures market without having any obligations to actually deliver or take delivery of copper cathodes. It is only important that, as also the speculators, the contracts that the company enters at the LME futures market always have the same delivery date, so that they cancel each other out and physical delivery can be avoided.

2.13 Hedger vs. speculator

In conclusion, a hedger that does not plan to deliver or take delivery of cathodes into or from the LME warehouses, does the same trades as a speculator, in order to offset adverse price movements of physical copper materials that he currently owns. When a copper scrap trader buys any type of copper scrap, he automatically (if he wants it or not) speculates on raising prices. Therefore, the scrap trader will decide to go to the LME futures exchange market and speculate on falling prices. In the end, the gain that he made on one side will be offset with the loss that he made on the other side. This is why he is considered to be a hedger. If he only opens a trade on one side (on the physical market or the LME exchange market) a loss will not be covered with a gain or vice versa. Therefore, such participants are considered to be speculators.

2.14 Remaining risk

As outlined in the scenario above, a scrap trader that buys copper scrap at the LME price minus a deduction and later sells the copper scrap at the LME price minus a smaller deduction can hedge the price risk he is exposed to and therefore fully profit from the difference of the two deductions. This scenario theoretically holds, as long as the deductions are agreed and fixed in advance. However, this is not always the case. Since the deductions are set by the market, they are volatile themselves and can change over time.

2.15 Deductions for raw materials

The decision of a smelter or refinery to change the deductions for a certain recycling material can have different causes. On one side, changes in their production cost might have occurred (for example higher electricity costs, labour cost, etc) which have to be covered. On the other side, smelters and refineries use the deduction to give incentive to suppliers to deliver more or less material. In times of large supply of one certain quality of copper scrap, they will increase the deduction (decreases the paid price) and in times of a shortage, they will decrease the deduction (increases the paid price). This creates a classical supply and demand mechanism for each individual type of copper scrap. However, this also leads to the consequence that the price of a certain copper scrap quality does not always move exactly parallelly to the LME price.

Nevertheless, since the deduction is, compared to the LME price, relatively small, the scrap price will still move very similar to the LME price.

2.16 The hedge ratio

In the example above, in which a scrap trader buys 26.31 tonnes of copper scrap with a content of 25 tonnes of payable copper, the trader hedges price risk with 25 tonnes of copper cathodes on the LME markets. This would be an example of a hedge ratio of 1.00. This means, on 25 tonnes of payable copper content bought, 25 tonnes of copper cathodes were promised to be sold at the LME as a hedge. In this scenario, it is assumed that both prices move perfectly simultaneously. This is a precondition for such a hedge to be efficient.

However, as further outlined, parallel price movements are not always given. The paid price for copper scrap moves similarly to the LME price, but not exactly parallelly. In reality, the paid price for copper scrap material might change proportionally stronger or weaker compared to the LME price, depending on how refineries and smelters set the deductions. If they set high deductions when LME prices are high, and low deductions when LME prices are low, the actually paid copper scrap price moves proportionally less than the LME price. This could, for example, mean that if the LME price would rise by 5%, the paid price for copper scrap might only rise by 4.5%.

Under these conditions, an LME price increase of USD 500 per tonne would only lead to a price increase of USD 450 per tonne of payable copper content. A hedger that applied a hedge ratio of 1.00 would then have to offset a gain of USD 450 with a loss of USD 500, essentially leaving him with USD -50, instead of the desired USD 0.00.

If he would have applied a hedge ratio of 0.90 instead of 1.00, this would be different. Since he would have bought 22.5 tonnes in futures contracts, he would only have lost 22.5 tonnes times USD 500. The gain on the physical refinery material would have stayed the same (25 tonnes times USD 450). Overall, on both sides he would have made a loss respectively a gain of USD 11’250, which offset each other perfectly, leading to the desired result of USD 0.00. In this scenario, the hedge ratio of 0.9 would also have been more efficient if the price had fallen, since a drop of 5% on the LME would only cause a drop of 4.5% on the price of copper scrap.

In conclusion, under the hypothesis that the scrap price moves proportionally weaker than the LME price, a hedge ratio of 0.9 would be more efficient than the classical ratio of 1.00. However, it could also be the case that deductions for copper scrap are low (paid price increases) when the LME price increases and high (paid price falls) when the LME price falls. If this is the case, copper scrap prices would move proportionally stronger compared to the LME price and the optimal hedge ratio would be higher than one, for example 1.10.

Nevertheless, this assumes that there is a relationship between the deductions and the LME price levels. If such a relationship exists, the above mentioned and also in practice often applied hedge ratio of 1.00 would not be the most efficient hedge ratio and can cause unnecessary risk. The purpose of this research paper is to examine the ideal hedge ratio for two copper scrap materials (millberry and refinery material) and to explore different ways, how such a ratio could be further optimised. The research will also explore other aspects of the market respectively its influence on the copper scrap deductions.

2.17 The LME in perspective

Before the research will be described, the following paragraph is aimed to compare the LME copper futures market to the actual physical copper market. This should put the two markets in perspective and outline some of the effects, that the LME has on the overall market.

In the year 2018, a total of 38’599’069 lots with 25 tonnes of cathodes each have been traded on the LME futures market (The London Metal Exchange, 2018). This amounts to a total of 965 million tonnes of traded copper. This is approximately 34 times the actual demand for physical copper in the same year (28 million tonnes). Calculated with an approximated average price per tonne of USD 6’541.50 (unweighted average official price in 2018) (Bloomberg L.P., 2020), this results in a total volume of USD 6’312 billion. In comparison, the BIP of Switzerland was 705 billion in the same year (approximately 9 times lower).

However, it is important to remember that not all traded contracts will result in an actual payment or in a physical delivery. Most of the contracts are closed out with another contract and only the difference will be settled in cash. In fact, contracts are closed out so often, that before settlement less than 1% of all LME contracts remain. Only those result in physical delivery and full payment (The London Metal Exchange, 2018).

2.18 Market of last resort

If an LME contract is physically settled, the lot has to be taken out of an LME warehouse. The amount of copper that is delivered from or to the LME warehouses can be observed on the daily published stock data. If warehouse stock rises, more physical deliveries have taken place than physical pickups of cathodes. In other terms, physical producers of cathodes did not find physical buyers for their cathodes and decided to sell the oversupply on the LME. This illustratively shows, how the LME absorbs copper in times of oversupply and therefore balances the market. In times of high demand, respectively when physical buyers cannot find physical producers of cathodes directly outside the LME, they can turn to the LME and buy cathodes over futures contracts there. This is the reason, why the LME futures market is often described as “Market of last resort” for physical producers and physical buyers (The London Metal Exchange, 2018).

3 Literature review

3.1 Hedge effectiveness

As already mentioned above, the aim of this research is determining a hedge ratio between copper scrap prices and copper futures prices. Estimating a hedge ratio in itself is nothing new. One of the first who estimated the optimal hedge ratio by means of statistical mathematics and portfolio theory was Ederington in 1979. He wanted to find out, with what ratio T-Bills are optimally hedged by means of T-Bill Futures (Ederington, 1979).

Before his research, most hedgers applied the today often called “naïve” hedge ratio of 1.00. It was assumed that expected futures prices must in average move simultaneously to spot prices since they represent the same product. Ederington proofed in his paper that this is not always the case. He suggested that even a pure risk-minimizer might prefer a hedge ratio that is lower than 1.00 (Ederington, 1979). A hedge that aims to reduce risk to a minimum, rather than finding an optimal risk-return-relationship is called minimum-variance-hedge (Hull, 2015). Also the hedges calculated in this paper are considered to be minimum-variance-hedges.

Ederington’s calculations were based on linear regression, where a statistical calculation is used to determine, how the changes of the two prices are connected. In concrete terms, a resulting number of 0.5 would mean that, statistically, every time the spot price increased by USD 1.00, the futures price rose by USD 2.00. When the cash price decreased by USD 1.00, the futures price decreased by USD 2.00. The two prices therefore in average move simultaneously with a ratio of 0.5. This number is then also applied as the optimal hedge ratio (Ederington, 1979). For his calculations, Ederington applied the Ordinary Least Square Method (OLS).

Ederington’s work was the basis for much research that followed. Hedge ratios were calculated for many different futures markets and a wide variety of products. Some examples are live cattle in Brazil (Pinho, Araújo, & de Camargos, 2017), precious metals markets (Nishi, 2019), crude oil (Balea, 2014) (Gadmor, 2006) (Shiraya & Takahashi, 2012), stock indices such as S&P 500, FTSE 100 and the MSCI-SWI (Hsu, Tseng, & Wang, 2008) or agricultural commodities such as wheat (Dinica & Dinica, 2015) or soybeans (Moody, 2017).

The OLS model is not the only way to estimate the optimal hedge ratio. Models such as ARCH (Engle R. F., 1982), GARCH (Bollerslev, 1986) or the DCC Model (Engle & Sheppard, 2001) are different approaches to estimate hedge ratios. However, some studies in certain markets suggest that these more sophisticated models do not always outperform the OLS or a Rolling Windows OLS in terms of efficiency of the hedge ratio (Lien, Tse, & Tsui, 2002), (Bystrom, 2003), (Yu, Moon, & Hong, 2009). It can also further be said that the estimated ratios from the different models do often not deviate considerably from each other.

Also in the LME base metal markets a large variety of research has been conducted. Dewally & Mariott (2008) calculated the optimal hedge ratio on hedging horizons ranging from 1 day to 8 weeks for the six base metals traded on the LME (aluminium, copper, lead, nickel, tin and zinc). Their findings show that short-term hedging (shorter than one week) tends to be inefficient at any hedge ratio. On a range of 1 to 8 weeks, hedge efficiency increased with longer horizons (Dewally & Marriott, 2008). Also the optimal hedge ratio was higher on longer horizons than on shorter horizons. In copper, for example, the optimal hedge ratio for a horizon of one week was at 0.909. The ratio then increases gradually with longer horizons. The longest horizon that was tested (8 weeks) resulted in an optimal hedge ratio of 1.026 (Dewally & Marriott, 2008). This means, over a hedge horizon of 8 weeks, it would have made sense to have a 2.6% higher exposure to the copper futures than to actual physical cathodes in order to decrease the volatility of the overall portfolio during the tested period.

The findings of Dewally & Mariott are generally in line with the findings of Chen, Lee & Shrestha (2004), who estimated the optimal hedge ratio and hedge horizon in a large variety of markets, including commodities, currencies and stocks. They generally conclude that on longer hedge horizons, the hedge ratio of 1.00 becomes more and more efficient. They also concluded that on shorter hedge horizons, a hedge ratio smaller than 1.00 should be considered (Chen, Lee, & Shrestha, 2004).

Nevertheless, the possibility to choose the hedge horizon might not always be given for physical commodity traders. The moment, when to buy and sell might not be in his choice, which leads to certain boundaries when deciding on what horizon to hedge.

Dewally & Mariott focused in their study on the metal market between July 1998 and October 2006. A more recent study by Dinica & Armeanu (2014) conducted the same calculations, but on a larger and more recent data sample (April 2000-September 2013). They additionally expanded Dewally & Mariott's research by adding an out-of-sample comparison. Their results were in line with Dewally & Mariott. They found increasing hedge efficiency and increasing hedge ratios over longer hedge horizons (Dinica & Armeanu, 2014). They further also tested on hedge horizons from 8 to 12 weeks, where the optimal hedge ratio kept relatively stable at approximately 1.00 (Dinica & Armeanu, 2014). Overall, Dinica & Armeanu discovered slightly lower hedge ratios than Dewally & Mariott on all horizon. This could be due to the fact that prices were less volatile between 1998 and 2006 (Dewally & Mariott) than between 2000 and 2013 (Dinica & Armeanu). Dinica & Armeanu's study was further affected by the financial crisis in 2008, what could also have an influence on the results.

Further important are Dinica & Armeanu's findings in the out-of-sample hedging effectiveness comparison. It was again shown that longer-term hedging is more effective and also that the effectiveness between different models such as the OLS and GARCH model is very similar (Dinica & Armeanu, 2014).

3.2 Cross hedging

The research reviewed above tested the hedge efficiency of the markets itself. This means the researchers tested, how efficient the market allows minimizing price risk when holding the actual underlying of the traded futures contracts. For example, copper cathodes would be hedged with copper futures. However, the aim of the research at hand will be testing the hedge efficiency when holding a product that in itself is not the underlying, but something similar to the underlying, in this case copper scrap. For this, a cross-hedge needs to be calculated. The models that are used for this are in its fundamentals the same, but instead of regressing the spot price of the underlying on the futures price, the spot price of the hedged product is regressed on the futures price. The mathematical methodology for such a model, using the ordinary least square method, is presented by Hull (2015) in his book "Options, Futures and other Derivatives" in chapter 3, where a formula for the minimum-variance-hedge ratio is presented (Hull, 2015). He illustrates the formula with an example, where jet-fuel is hedged by means of heating oil futures. This example has also been examined in the real market by Adams & Gerner (2011). It was outlined that such a cross-hedge is efficient on different horizons (one to twelve months), given that the hedge ratio is set correctly (Adams & Gerner, 2012).

Other researchers have calculated cross-hedges in other markets with different products. Kim, Brorsen & Yoon (2014) examined how to hedge winter canola from North Dakota by using different CBOT or WCE futures (Kim, Brorsen, & Yoon, 2014). Goodwin & Zhao (2012) used corn futures contracts to cross-hedge grain sorghum and Kansas wheat futures contracts to cross-hedge barley (Zhao & Goodwin, 2012). Further, Hayenga & DiPietre used live hog futures to cross-hedge wholesale pork products (Hayenga & DiPietre, 1982). The research on cross hedging makes clear, that a cross-hedge can only be effective when a relationship between the underlying product of the futures and the hedged product exist. Only in such a case, both prices move similarly to each other.

3.3 Research question

Although there is already a wide range of research that determines the hedge effectiveness between futures markets and their underlying products respectively also related products, hardly any specific research exists about cross hedging individual types of copper scrap. Aruga & Managi (2011) examined the relationship between the prices of different types of copper scrap and COMEX copper futures market prices. They found that a relationship exists for copper scrap with high copper content such as millberry or refinery material, but there appears to be no relationship for materials that have lower copper content such as brass (copper alloyed with zinc) (Aruga & Managi, 2011). Aruga & Managi did however not outline to what extent the prices are correlated or with what hedge ratio the relationship could be used to hedge the price risk of copper scrap materials.

In practice, it is very common to apply the naïve hedge ratio of 1.00. For copper scrap traders, this can lead to suboptimal portfolios with higher price fluctuations than necessary. Under many circumstances, this can also cause higher hedging costs. The aim of this research is therefore to find the optimal hedge ratio for certain copper scrap materials (millberry and refinery material) and test it with an out-of-sample test. This research will also explore different determinants of the copper scrap market that might lead to an improvement of the hedging.

The findings of this research will help scrap trading firms to optimize their copper portfolios by reducing price volatility. Less adverse price movements generally allow firms more stable projections of future cost and profits, which can give them competitive advantage. By examining other determinants of the market, insight might be discovered that can help scrap traders to understand the copper scrap market more in-depth.

4 Methodology

4.1 Data

The data that is used in this research consists of various price and stock data. In detail, the data set contains monthly price data of the LME three-months copper contract and the two-days copper contract (cash-price). Since copper scrap prices in the physical market are often derived from the official price determined in the second ring, those prices are used in this research. Since monthly data is required, always the price that was valid on the last trading day of the month is included. This is important since the LME price data needs to match the subsequently described deductions for copper scrap. Also, since the deductions used in this research are always determined on the basis of LME-prices, only LME-prices are considered and data from other exchanges is not included. The data was taken from Bloomberg.

Further included in the data set are the deductions that are applied to determine the prices for millberry and refinery material. In the scrap trading industry, it is common to apply the deductions on the lower of the three-months-price or cash-price. Therefore, the lower of both minus the deduction results in the price that is paid per tonne of copper content of the respective material.

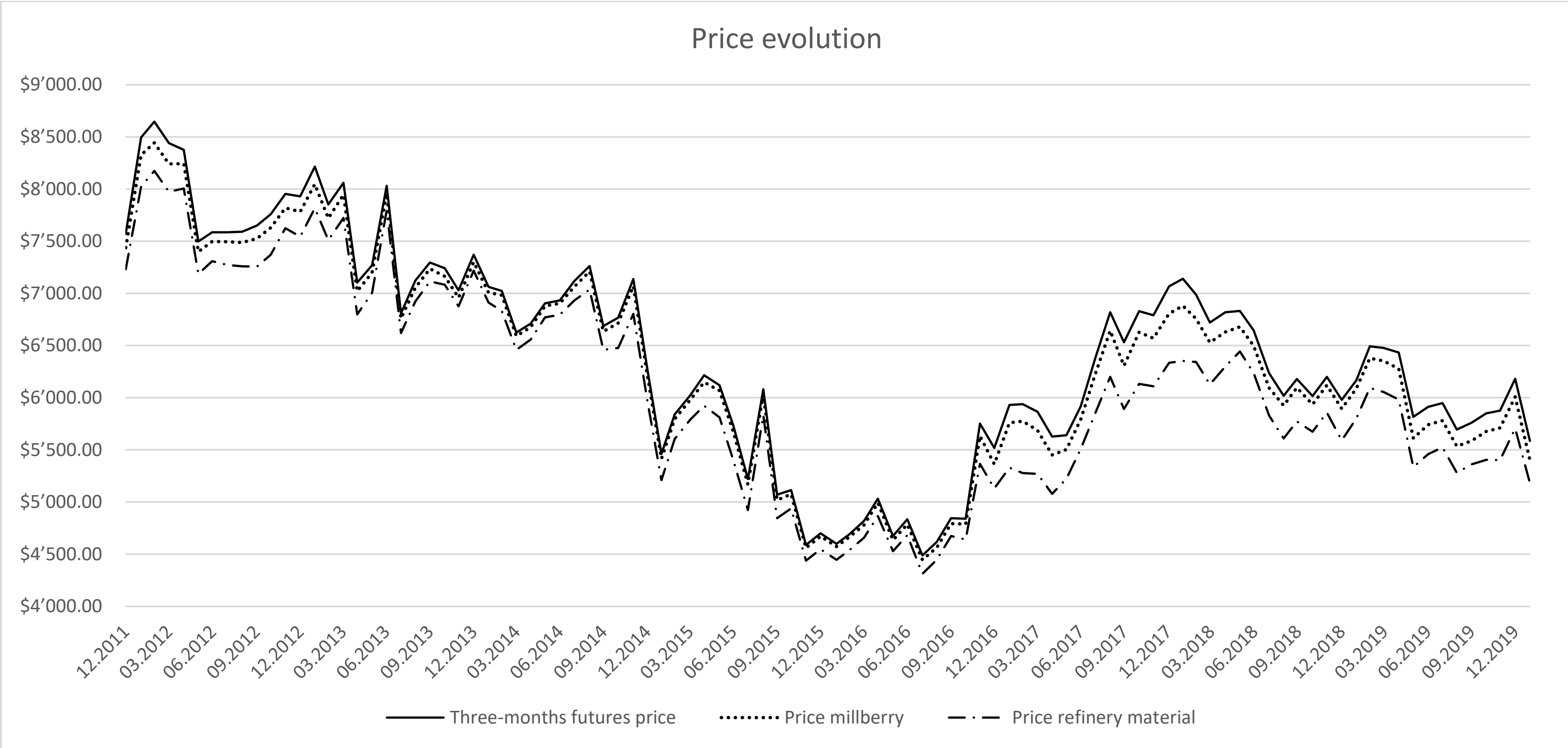
The deductions have been generously provided by a swiss scrap trading company that conducts on every month's end a survey among large smelters and refineries in Europe. The aim of the survey is determining the deductions that the market is applying at this point in time when buying copper refinery material or millberry. While the scrap trading company needs this information for their month's end valuations, it is also suitable in this research to track the evaluation of copper scrap prices. Since the scrap trading company mainly conducts its business in Europe, the deductions are indicated in Euros and then converted into US Dollars. In order to have comparable exchange rates, the EUR/USD spot rates indicated by the Bloomberg FX Fixings (BFIX) of the corresponding days are used. The BFIX is currently also applied in the industry as the standard conversion rate.

Further included in the data set is stock data from the LME Warehouses. The stock data shows, how many metric tonnes (mt) of copper cathodes were stored on a given day globally in LME warehouses. This data has been taken from Bloomberg as well.

The following chart shows a descriptive statistic of the data set.

	Deduction millberry in EUR	Deduction refinery material in EUR	LME cash official price mean in USD	LME three months official price mean in USD	BFIX EUR/USD	Warehouse stock data in metric tonnes
Mean	-80.3972611	-282.1685902	6442.602041	6441.007653	1.201441837	281541.5816
Standard Error	4.661689547	13.37854695	103.4035438	103.2886879	0.010329037	11708.77429
Median	-69.96550073	-260.1590941	6463	6454.75	1.171775	259237.5
Standard Deviation	46.14837206	132.4408577	1023.642858	1022.505843	0.102252254	115910.9518
Sample Variance	2129.672244	17540.5808	1047844.701	1045518.199	0.010455523	13435348749
Kurtosis	-1.252393947	-0.30229873	-0.58814982	-0.604552447	-1.312035843	2.173373379
Skewness	-0.408384537	-0.614993025	0.012673731	0.003250015	0.364278018	1.400244188
Range	156.6998878	519.9419123	4170.5	4157.25	0.33465	533800
Minimum	-176.6982425	-619.9336859	4486	4488.75	1.05035	128475
Maximum	-19.99835472	-99.99177361	8656.5	8646	1.385	662275
Count	98	98	98	98	98	98

The data set reaches from December 2011 to January 2020. The following graphs are aimed to put the data into perspective by means of time series:


Price evolution
$9'000.00
$8'500.00
$8'000.00
$7'500.00
$7'000.00
$6'500.00
$6'000.00
$5'500.00
$5'000.00
$4'500.00
$4'000.00
12.2011
03.2012
06.2012
09.2012
12.2012
03.2013
06.2013
09.2013
12.2013
03.2014
06.2014
09.2014
12.2014
03.2015
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12.2015
03.2016
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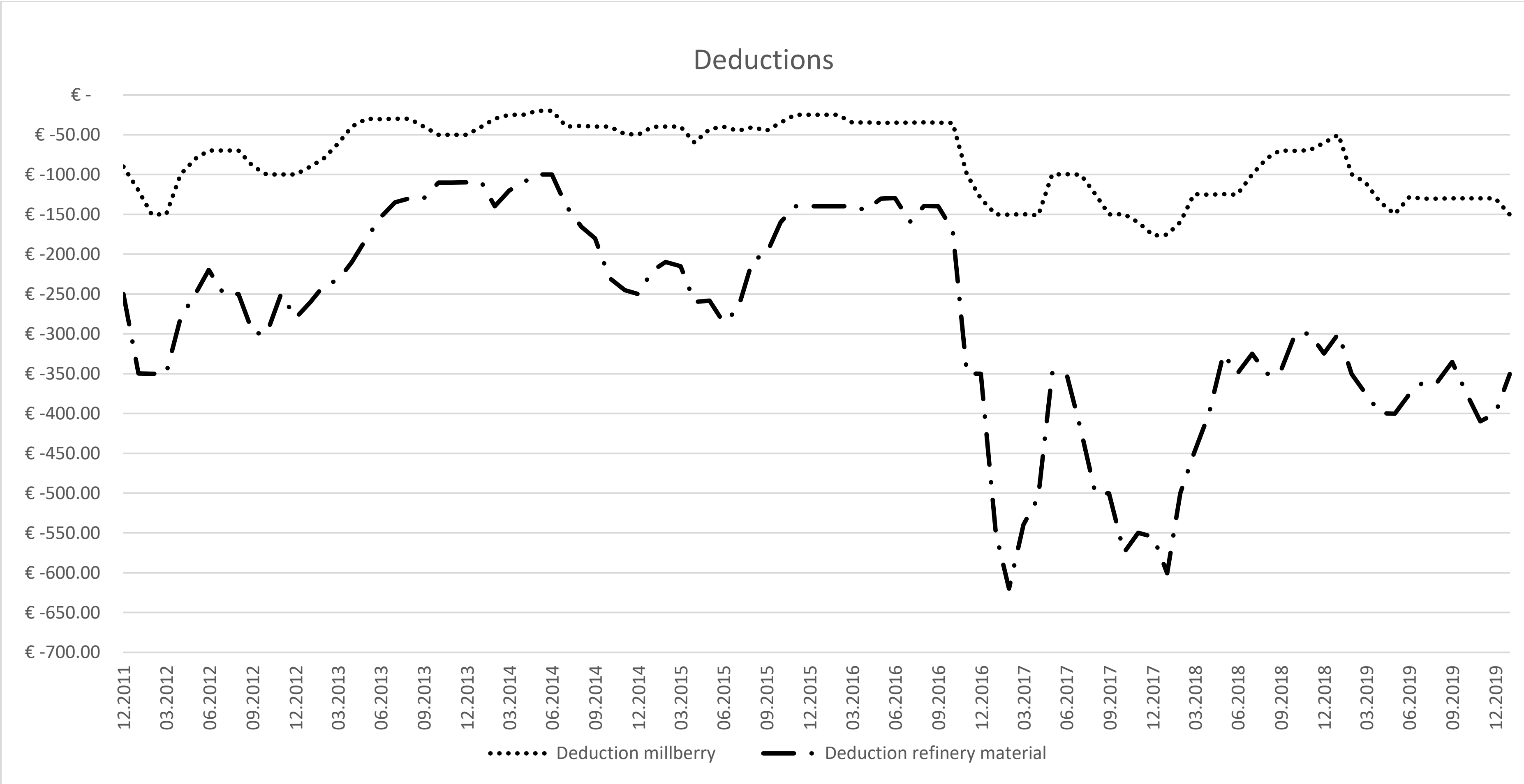
12.2016
03.2017
06.2017
09.2017
12.2017
03.2018
06.2018
09.2018
12.2018
03.2019
06.2019
09.2019
12.2019
Three-months futures price
Price millberry
Price refinery material


Deductions
€ -
€ -50.00
€ -100.00
€ -150.00
€ -200.00
€ -250.00
€ -300.00
€ -350.00
€ -400.00
€ -450.00
€ -500.00
€ -550.00
€ -600.00
€ -650.00
€ -700.00
12.2011
03.2012
06.2012
09.2012
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12.2017
03.2018
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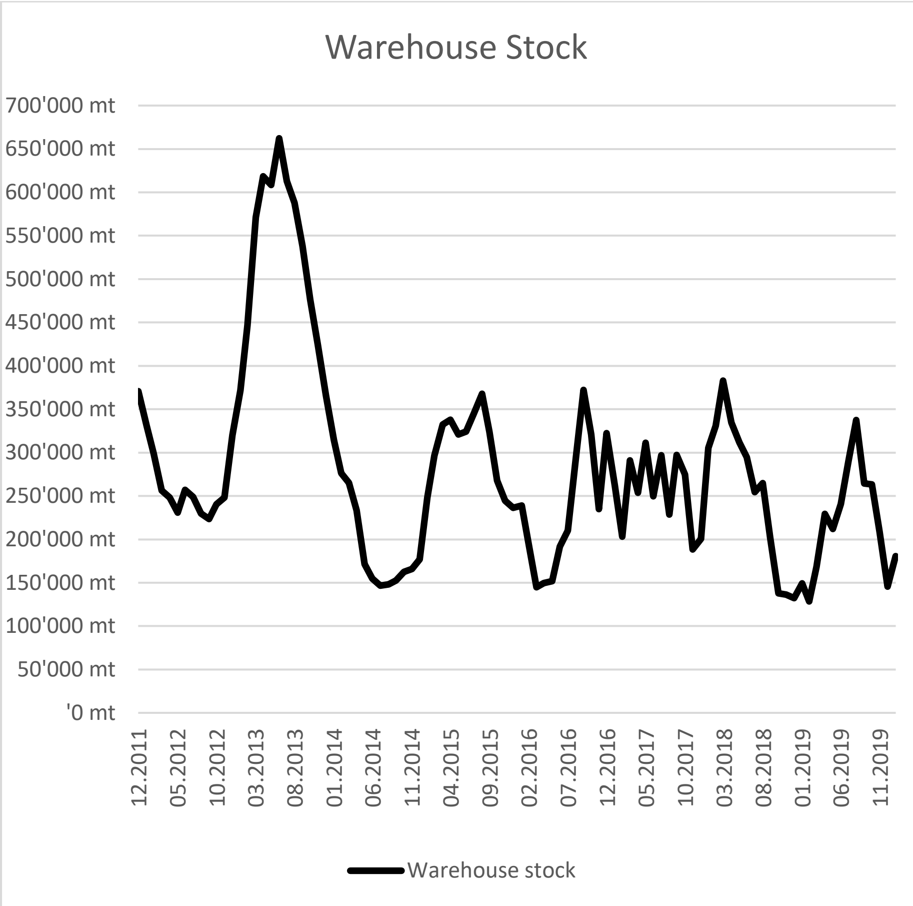
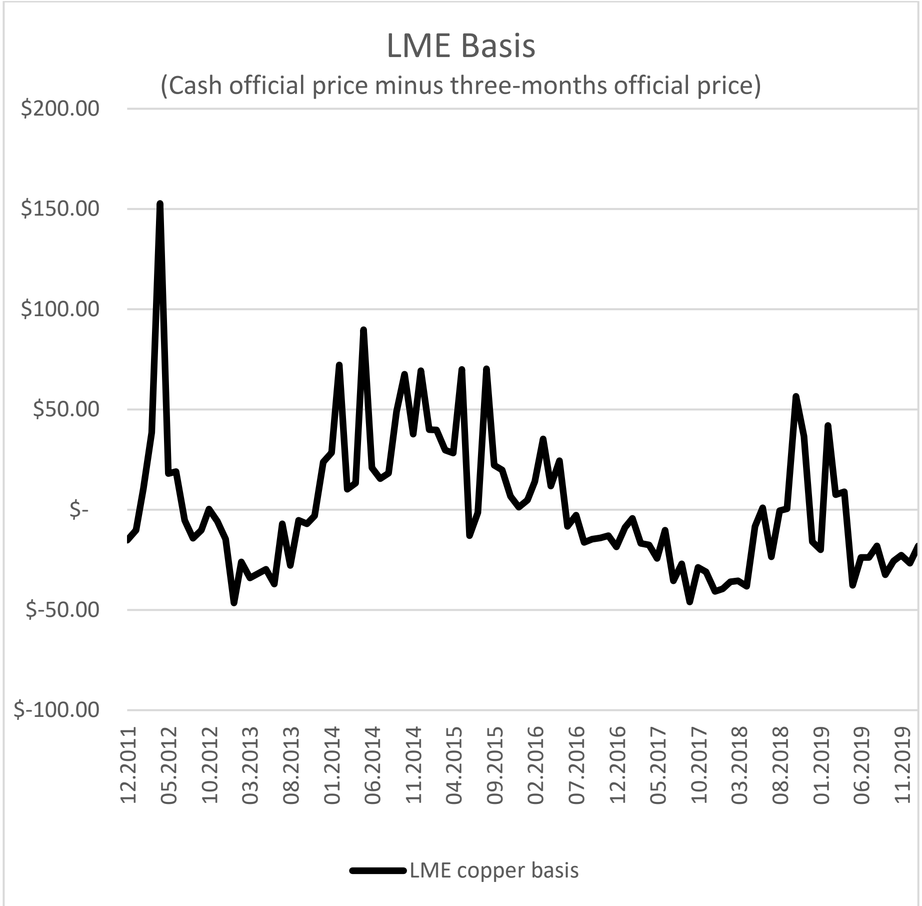
09.2018
12.2018
03.2019
06.2019
09.2019
12.2019
Deduction millberry
Deduction refinery material


Warehouse Stock
700'000 mt
650'000 mt
600'000 mt
550'000 mt
500'000 mt
450'000 mt
400'000 mt
350'000 mt
300'000 mt
250'000 mt
200'000 mt
150'000 mt
100'000 mt
50'000 mt
'0 mt
12.2011
05.2012
10.2012
03.2013
08.2013
01.2014
06.2014
11.2014
04.2015
09.2015
02.2016
07.2016
12.2016
05.2017
10.2017
03.2018
08.2018
01.2019
06.2019
11.2019
Warehouse stock


LME Basis
(Cash official price minus three-months official price)
$200.00
$150.00
$100.00
$50.00
$-
$-50.00
$-100.00
12.2011
05.2012
10.2012
03.2013
08.2013
01.2014
06.2014
11.2014
04.2015
09.2015
02.2016
07.2016
12.2016
05.2017
10.2017
03.2018
08.2018
01.2019
06.2019
11.2019
LME copper basis

4.2 Linear regression

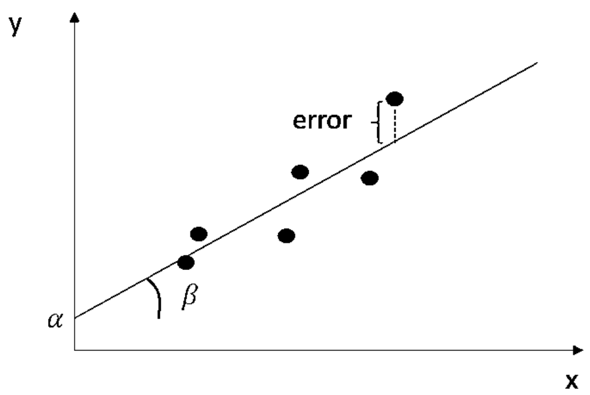
In this research, a variety of hypotheses are examined. Although every hypothesis requires its own analytical approach, most of them have linear regression as their core element.

Linear regression assumes that the relationship between two variables can be explained by the following formula:

$$Y = \alpha + \beta X + \varepsilon$$

X is thereby describing the value of the independent variable and Y the value of the dependent value. ε is the error term. The error term is the part of the variation in Y, that could not be explained by a change in X. The parameter β represents the relationship, with which Y reacts to a change in X. In other terms, if β is calculated to be 0.6 and X increases by 100, Y is estimated to increase by 60. (α represents the value of Y when X is 0. However, this value will not be relevant in this research.)

As soon as the formula is established, it can be applied to estimate values of Y, based on values of X. The more the actual Y deviates from the estimated Y, the larger will be the error term. Consequently, the smaller the error-terms are, the better are the estimates for Y.



Graphically expressed, the ordinary least square method plots each observation (an X-value and the corresponding Y-value) in a diagram. Then it tries to fit a straight line between the observations in the angle, that comes the observations the closest. The slope of that straight line will then represent β. With every time X increases by 1, Y increases by β.

The formula to calculate β is given by:

$$\beta = \rho_{xy} \frac{\sigma_y}{\sigma_x}$$

It is important to note that the linear regression model is a mathematical model that helps to make better estimates for Y, based on values of X. However, although Y depends on X, Y can additionally also be influenced by other variables, that are not considered in the model. In consequence, it happens that the estimated Y deviates from the observed Y, what then leads to an error-term ε.

It can also be the case that Y only slightly (or even not at all) depends on X. In that case, β would be very close to 0 (the fitted line would be horizontal) and large error-terms would occur. A β close to 0 would express that, if X changes by one, Y does not change. However, since Y than still can change due to not considered variables, large error-terms would appear. In this case, X would not be an effective variable to predict Y.

How effective a given X variable is to predict the values of Y is indicated by R^2. This value depends largely on how strong X and Y are correlated with each other. An R^2 of 0.8 would mean, that 80% of the change in Y can be explained by the change in X. Put differently, the higher the R^2, the more precise are the predictions and the smaller are the error-terms. R^2 is calculated with the following formula:

$$R^2 = 1 - \frac{SS_{RES}}{SS_{TOT}} = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \overline{y})^2}$$

5 The optimal hedge ratio

5.1 The optimal hedge ratio vs. the naïve hedge ratio of 1.00

To determine the ideal hedge ratio in the time period given by the data set, the cross-hedge ratio needs to be calculated. In order to do so, it needs to be estimated, how the price for copper scrap changed when the LME-price changed. As explained above, this can be reached by regressing the paid copper scrap prices on the LME copper futures prices. Also Hull (2011) proposed this according to the following formula, which is an application of the formula for β from linear regression:

$$h = \rho_{\Delta F, \Delta S} \frac{\sigma_{\Delta S}}{\sigma_{\Delta F}}$$

In this formula, $\sigma_{\Delta S}$ describes the standard deviation of the change in the spot price (S) of the hedged product (here copper scrap) over the hedged period. $\sigma_{\Delta F}$ describes the standard deviation of the change in the futures contract prices (F) over the same period. $\rho_{\Delta S, \Delta F}$ describes the correlation between both (ΔS and ΔF). Analogously to β, h represents the relationship between ΔS and ΔF and therefore also the hedge ratio. If for example h results to be 0.8, this would mean that when the futures price changed (increased or decreased) by USD 10.00, the copper scrap price changed in average by USD 8.00 in the same direction.

In order to create a realistic scenario, this research assumes that a copper scrap trader buys copper scrap at the end of month 0 and sells it at the end of month 3. At the same time, he enters a hedging agreement on the LME by which he sells a three-months contract at the end of month 0 and buys a cash contract shortly before the end of month 3 to close the position. This results in a hedge horizon of three months. (For hedge horizons of two or one month, the futures contract would not be closed in three months with a cash-contract, but in two or one month with a one- respectively a two-months contract.)

It is assumed that the scrap trader enters such a hedge at every month's end. The futures contracts together with the copper scrap that the trader physically owns form his overall portfolio.

However, it needs to be considered that the difference between the paid futures price and the received cash price did not only occur due to changes in the price for copper cathodes but also due to storage cost and interest. This means, even if the underlying price would not have changed, the copper scrap trader would still have made a certain gain (given the market was in contango). The three-months contract that he sold included cathodes plus storage and interest for three months. However, the cash contract that he bought only included the cathodes respectively nearly no storage or interest. Therefore, in sum, the scrap trader would have made a gain in the amount of storage cost and interest.

Nevertheless, in this research, it will be assumed that the scrap trader uses this gain in order to pay for the physical storage that is needed to store the hedged copper scrap and considers the interest as a compensation for the money tied in the physical copper scrap. If the hedge should require that the scrap trader buys the three-months contract and sells the cash contract, storage cost and interest would not be gained, but lost. However, since such a hedge only occurs when he physically promised copper scrap to a client in the future, he is theoretically storing copper for this client up to delivery. For this service, the scrap trader should get a compensation from his client. In this research, it is assumed that the loss of storage and interest in the futures contracts and the money received for storing the physical copper scrap come out even.

In short, storage cost and interest that is paid on the physical side is assumed to be reimbursed on the financial side and vice versa. Consequently, in order to properly calculate the effectivity of a hedge, storage cost and interest must be excluded on both sides. Since the price change in copper scrap (ΔS) is calculated with spot prices directly, storage cost and interest are already excluded and only the pure price change is considered. However, this is not the case on the futures side of the calculation. There, the difference between the three-months contract and the cash contract plus storage cost and interest should be taken into account. Since the cash price plus storage and interest for three months equals again the three-months futures price, the difference between the three-months futures prices at the end of month 0 and the three-months futures price at the end of month 3 (ΔF) is considered directly. This then purely shows the price change of the underlying without the dilution of storage cost or interest.

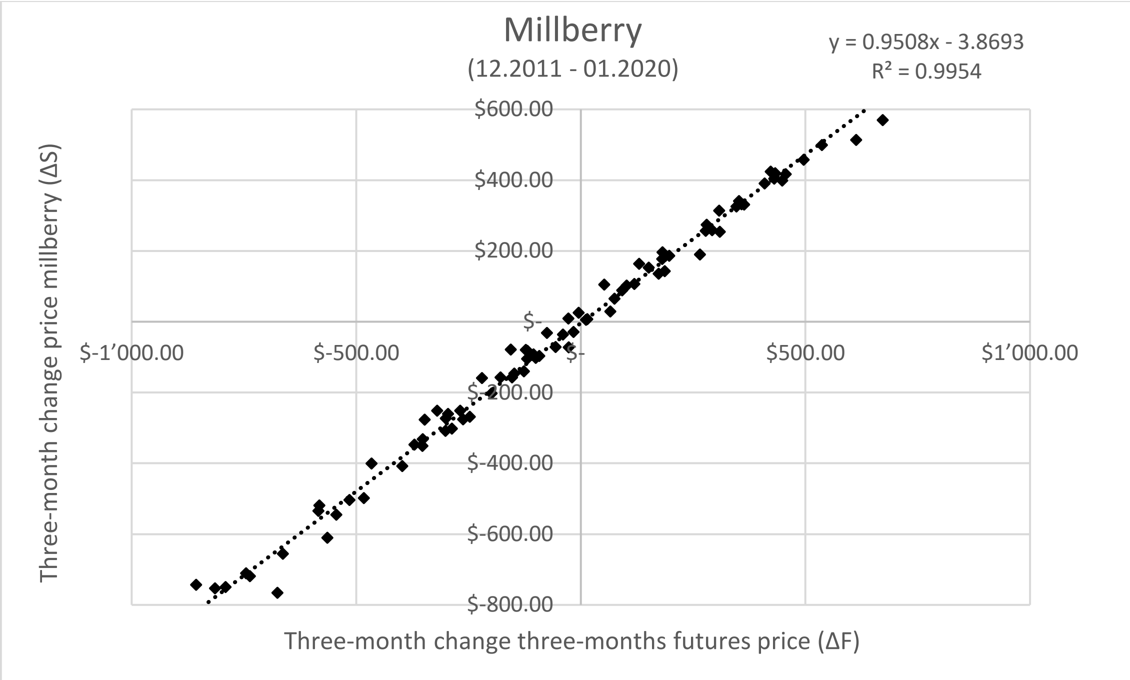
By regressing ΔS on ΔF with the above-mentioned formula, the following hedge ratios result for hedge horizons of one month, two months and three months. Since those ratios reduce the error-terms to the minimum, these hedge ratios are considered to be optimal.

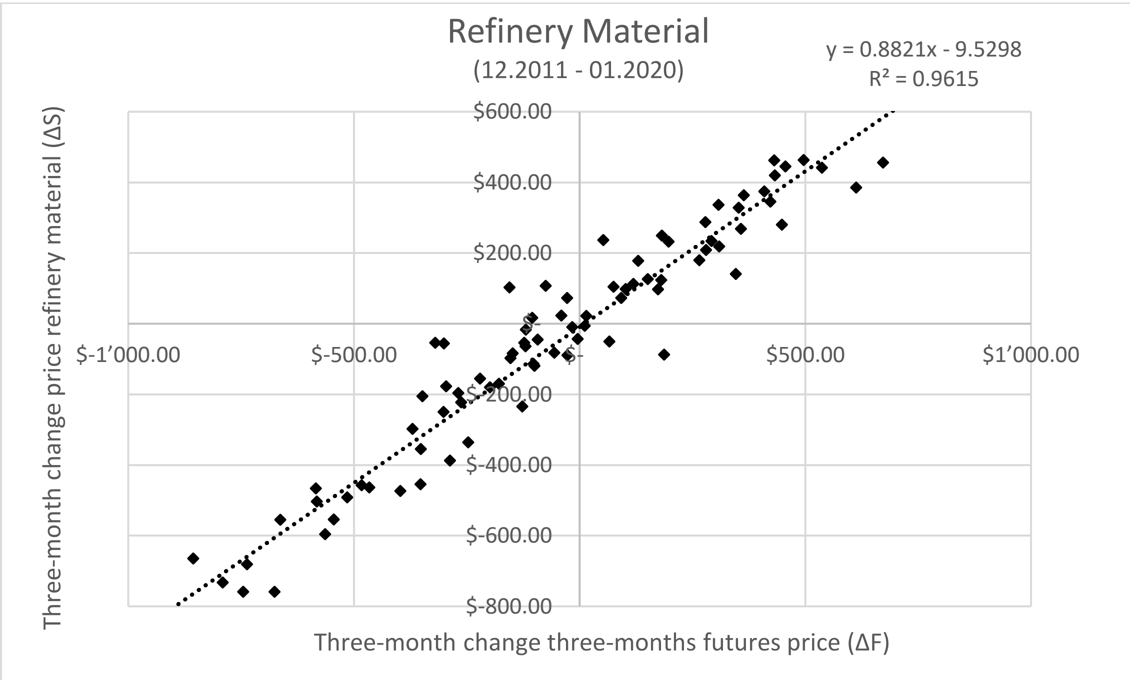
Hedge horizon	Millberry	Refinery Material
1 month	0.98238	0.94720
2 months	0.96556	0.91362
3 months	0.95078	0.88213

It can be observed that on shorter hedge horizons, prices of copper scrap moved more similar to LME prices than on longer horizons. An explanation for this could be that deductions for both types of copper scrap are in the short-run not as volatile. Therefore, if the deductions only change slightly, the prices will be very similar to each other and the optimal hedge will be closer to 1.00. However, over longer time horizons the change in the deduction can be larger, what turns the naïve hedge ratio of 1.00 more and more ineffective.

It is further observable that the optimal hedge ratio for millberry is much closer to 1.00 than the one for refinery material. This means that the millberry-price shows more similarity to the LME price than the one of refinery material. This could be due to the fact that the average deduction for millberry is with (USD -98.83) much smaller than the one for refinery material (USD -334.21) and also changes less in absolute terms. This deduction-structure is set this way by the market since millberry is with its 99.9% copper much more similar to cathodes than refinery material with 95%. Consequently, millberry can also be applied much later in the supply chain and does not have to be additionally purified.

This price-structure can also be observed in the following two scatterplots, which show the three-month change in futures prices (ΔF) on the x-axis and the three-month change in scrap prices (ΔS) on the y-axis.





Since the price-observations for millberry are closer together respectively closer to the trendline than the ones from refinery material, the fact that the price for millberry is closer connected to the copper futures price is supported. This is also indicated in the R^2. While the R^2 for millberry is at 99.5%, the R^2 for refinery material is at 96.1%. This indicates that the price for refinery material is slightly stronger influenced by factors other than the LME copper market. Since refinery material needs to be additionally refined before it is ready to be used, the cost occurring thereby are likely to be the cause of the larger error-terms respectively the lower R^2.

Considering the numbers above, it can be seen that for none of the hedge horizons the naïve hedge-ratio of 1.00 would have been optimal. Although it was close to 1.00 for millberry on the hedge horizon of one month, for all other horizons a hedge ratio lower than 1.00 would have been more efficient.

Since the aim of this research is finding the optimal hedge ratio for the minimum-variance-hedge, the effectivity of the calculated hedge ratios can be tested by simulating the hedges over the entire time period and then calculating the volatility of the overall portfolio. The volatility is indicated by standard deviations (σ) from the mean. The lower the volatility of the overall portfolio, the less price risk occurred and the more effective was the hedge. By applying the above indicated three-months hedge ratios, the following standard deviations result:

Standard Deviation (σ)	Millberry	Refinery Material
Unhedged portfolio:	966.75 $	962.66 $
Hedged with ratio 1.00:	42.54 $	111.18 $
Reduction of σ compared to unhedged portfolio:	-95.6%	-88.5%
Hedged with optimal ratio:	33.85 $	92.47 $
Reduction of σ compared to unhedged portfolio:	-96.5% (-0.9%)	90.4% (-1.9%)
Reduction of σ compared to ratio 1.00:	-20.4%	-16.8%

In conclusion, it can be observed that even if the naïve hedge of 1.00 is already decreasing the portfolio volatility to a large extent, it is not yet optimal and leaves unnecessary volatility in the portfolio. A part of this volatility could have been reduced with a lower hedge ratio.

5.2 Out-of-sample test

The regression of ΔS on ΔF calculates the optimal hedge ratio that was valid during the time given by the data set. As above, this ratio can then be used to calculate, what the portfolio standard deviation would have been if this ratio had been applied during this time. But this is only a theoretical and backwards-looking calculation. Its results would only have been realizable if the exact future prices would have been known before entering every hedge. However, this is impossible.

In reality, the hedge ratio must be determined before future prices are known. This makes the above calculation only backwards-looking possible. The calculated hedge ratios can nevertheless serve as an estimation for future hedge ratios. Since the calculated ratios were optimal in the past, it could be assumed that there will be very similar ratios in the near future. This strategy to estimate future hedge ratios is common when hedging. To test its effectivity, the strategy can be simulated with an out-of-sample test.

In this research, several out-of-sample tests were conducted. Only this way, comparable values, that were realistically achievable, can be calculated. In such a test, the sample data is cut off at a certain date. Then, the price data before the cut-off date is used to calculate the optimal hedge ratio (calculation period). This ratio will then be applied to the price data after the cut-off date (application period). In a realist scenario, the cut-off date is the date when the hedger decides to use past price data to calculate the hedge ratio that he will apply in the future.

With the resulting data, it can then be checked if the calculated hedge ratio would have decreased the standard deviation of the portfolio compared to the naïve hedge ratio of 1.00.

In this research, the out-of-sample test contains three different scenarios with different cut-off dates. Since the range of the sample data is limited, an earlier cut-off date leads to less price data to conduct the regression with, but more price data to apply the hedge ratio onto. A later cut-off date leads to the opposite result. It is always assumed that the hedger's preferred hedge horizon was three months.

Out-of-sample test: Scenario 1	**Millberry**	**Refinery Material**
Calculation period:	12.2011 – 10.2016 (59 months)	
Application period:	11.2016 – 01.2020 (39 months)	
Optimal hedge ratio:	0.95738	0.92921
σ of portfolio with 1.00:	50.68 $	146.15 $
σ of portfolio with calculated hedge ratio:	44.27 $	129.48 $
Reduction of σ:	-12.66%	-11.41%

Out-of-sample test: Scenario 2	Millberry	Refinery Material
Calculation period:	12.2011 – 09.2017 (70 months)	
Application period:	10.2017 - 01.2020 (28 months)	
Optimal hedge ratio:	0.95313	0.88553
σ of portfolio with 1.00:	47.69 $	100.54 $
σ of portfolio with calculated hedge ratio:	44.45 $	94.96 $
Reduction of σ:	-6.81%	-5.55%

Out-of-sample test: Scenario 3	Millberry	Refinery Material
Calculation period:	12.2011 - 04.2018 (77 months)	
Application period:	05.2018 - 01.2020 (21 months)	
Optimal hedge ratio:	0.94800	0.87314
σ of portfolio with 1.00:	41.78 $	54.82 $
σ of portfolio with calculated hedge ratio:	45.24 $	61.01 $
Reduction of σ:	+8.28%	+11.29%

In-sample test: (from Chapter 5.1) (for comparison)	Millberry	Refinery Material
Calculation period:	12.2011 - 01.2020 (98 months)	
Application period:	12.2011 - 01.2020 (98 months)	
Optimal hedge ratio:	0.95078	0.88213
σ of portfolio with 1.00:	42.54 $	111.18 $
σ of portfolio with calculated hedge ratio:	33.85 $	92.47 $
Reduction of σ:	-20.4%	-16.8%

As observable, the out-of-sample test shows that in two of the three scenarios, the in advance calculated optimal hedge ratio would have decreased the standard deviation and therefore the volatility of the overall portfolio. However, in the third scenario, the hedge ratio would not have led to a reduction of the volatility, but to an increase. Even if in the last scenario, the application period is with 17 months relatively small, a decrease in the volatility could have been expected. The fact that this is not the case might be a hint that the optimal hedge ratio itself is volatile and changes over time. In order to examine this, it needs to be tested if the portfolio volatility could be decreased with a hedge ratio that changes dynamically on an ongoing basis. Such a hedge is called a dynamic hedge.

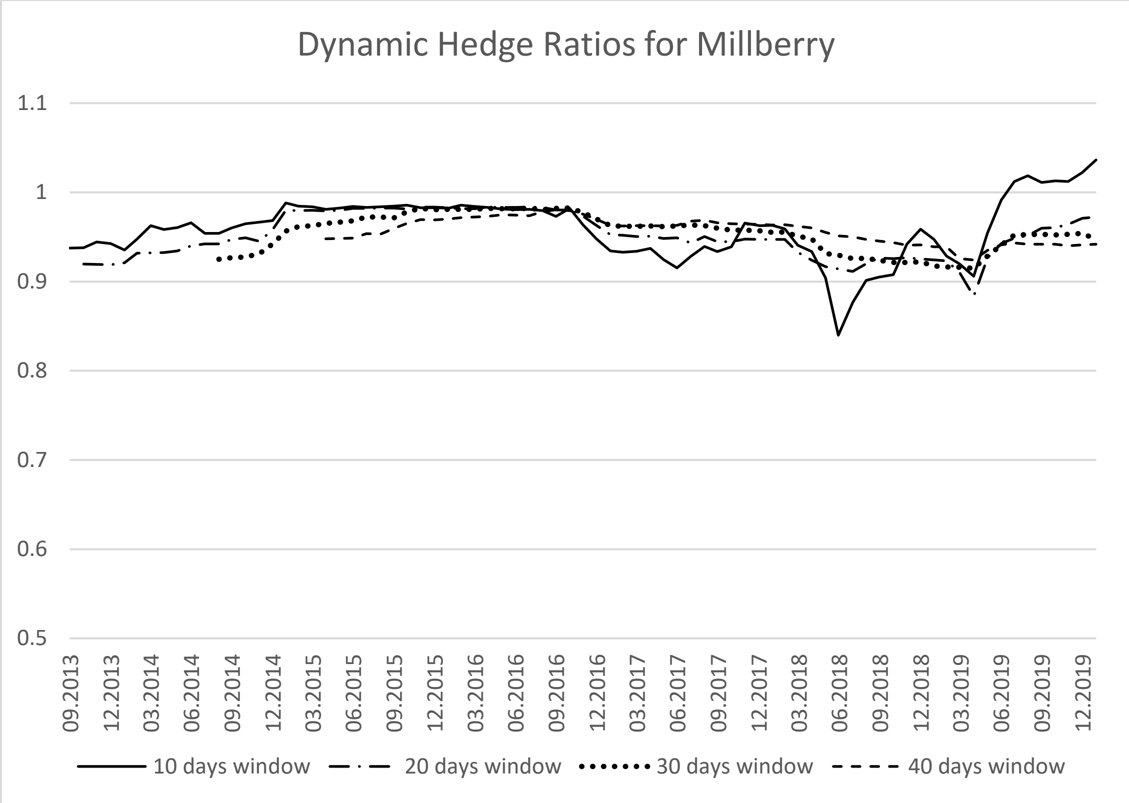
5.3 Dynamic hedge

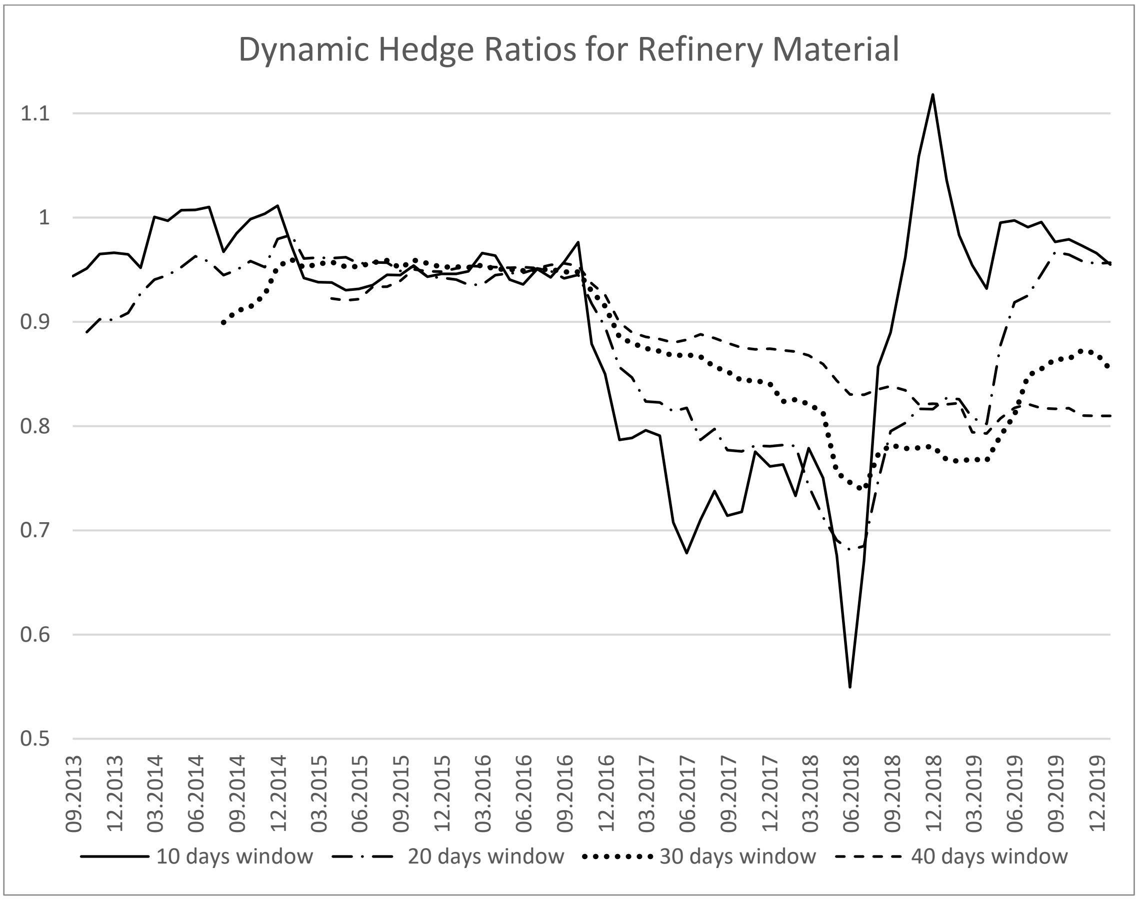
A dynamic hedge is a mathematical technique that builds on a combination of moving average and optimal hedge ratio calculation. When applying a dynamic hedge, the hedger will always use the price data of, for example, the past 10 months to calculate the hedge ratio. He will then apply this ratio in the hedge that is entered at that moment. Later, when he will have to enter a new hedge, he will calculate a new hedge ratio again with the price data of the last 10 months. Since it is assumed that the optimal hedge ratio changes over time, the dynamic hedge allows to update the applied hedge ratio every time before a new hedge is entered. The time that the hedger looks back to calculate the hedge ratio will in this research be called “calculation window”.

In order to create a scenario that is comparable to the calculations before, it will again be assumed that the hedger hedges over three months and enters a new hedge every month. With every time the hedger enters a new hedge, the new hedge ratio his calculated with a calculation window of 10 months. There will also be scenarios with calculation windows of 20, 30 and 40 months. Since the hedger enters a new hedge every month, the calculation window will also be shifted by one month every month.

5.3.1 Ratios

Before the results of the dynamic hedge will be calculated, it will be analysed how the hedge ratios changed over time. The more months that are included in the window, the flatter the line becomes. This also means that the ratios are less adjusted to the corresponding market situation. In fact, the 40-months hedge ratios are already close to the hedge ratio of the out-of-sample test with 59 months calculation period. However, the fewer months that are included in the calculation window, to more arbitrary the results can get and therefore they also become statistically less significant. The following graphs show the hedge ratios, that were calculated with a 10-, 20-, 30- and 40-months window.


Dynamic Hedge Ratios for Millberry
1.1
1
0.9
0.8
0.7
0.6
0.5
09.2013
12.2013
03.2014
06.2014
09.2014
12.2014
03.2015
06.2015
09.2015
12.2015
03.2016
06.2016
09.2016
12.2016
03.2017
06.2017
09.2017
12.2017
03.2018
06.2018
09.2018
12.2018
03.2019
06.2019
09.2019
12.2019
10 days window
20 days window
30 days window
40 days window


Dynamic Hedge Ratios for Refinery Material
1.1
1
0.9
0.8
0.7
0.6
0.5
09.2013
12.2013
03.2014
06.2014
09.2014
12.2014
03.2015
06.2015
09.2015
12.2015
03.2016
06.2016
09.2016
12.2016
03.2017
06.2017
09.2017
12.2017
03.2018
06.2018
09.2018
12.2018
03.2019
06.2019
09.2019
12.2019
10 days window
20 days window
30 days window
40 days window

When comparing the 10-months with the 40-months-window, it can be observed that the 40-months-window flattens out a lot of price volatility that is still considered by the 10-months-window. It can further be seen that up to the end of 2016, the ratios for both products were relatively constant at 0.97 for millberry and 0.95 for refinery material. However, during the time after 2016, both ratios were considerably more volatile.

During this period, an import ban in China limited the trading opportunities of certain qualities of copper scrap. In consequence, many traders were forced to reroute their goods to Europe which caused a short-term oversupply of copper scrap. As a result, smelters and manufacturers reacted by lowering their buying prices. The deductions increased considerably, thus causing the scrap prices and LME prices to diverge. Since China's import ban focused on lower-grade copper scrap, refinery material was more affected than millberry. Also in the subsequent years, China limited its scrap imports by means of import quotas, which continued to have an influence on volumes and therefore also on supply in Europe.

The deviation of the two prices might also be the reason, why the out-of-sample test was not always successful. The out-of-sample test calculated the ratio mainly based on prices that indicated a ratio of 0.97 and 0.95, but then applied it on prices that would have required ratios that are considerably lower or considerably higher. A dynamic hedge should be able to better adapt to such market situations. It can therefore be expected that the dynamic hedge will perform better than the static hedge from the out-of-sample test.

5.3.2 Improvement

If the price variations in the dynamically hedged portfolio are calculated, it becomes clear that the dynamic hedge did decrease the volatility of the portfolio and therefore improved the hedging.

Dynamic hedge (07.2015 -01.2020)	Millberry	Refinery Material
σ of portfolio with hedge ratio 1.00:	44.85 $	129.82 $
σ of portfolio with dynamic hedge (10 months): **Improvement:**	40.66 $ -9.33%	117.95 $ -9.14%
σ of portfolio with dynamic hedge (20 months): **Improvement:**	40.99 $ -8.60%	116.96 $ -9.90%
σ of portfolio with dynamic hedge (30 months): **Improvement:**	41.44 $ -7.59%	117.92 $ -9.17%
σ of portfolio with dynamic hedge (40 months): **Improvement:**	41.58 $ -7.28%	115.52 $ -11.02%

The table shows that with every window length, the variation of the portfolio has been decreased. The sample data used in this research would indicate, that for millberry ideally a window of 10 months should be used, while for refinery material a window of 40 months would have performed better. Nevertheless, the difference in performance between the different window length is comparably small, which makes it difficult to state that one window length would outperform another in the long-run. It can, however, be stated that a dynamic hedge would bring relatively solid improvement to the naïve hedge ratio of 1.00.

6 Other price determinants of the copper scrap market

In the previous chapter, the optimal hedge ratio and its effectivity has been explored using linear regression. The following chapter will now use linear regression in order to explore other determinants of the copper scrap market. The insight gained might help copper scrap traders to understand the market more in-depth, what could further be helpful when setting up the hedging strategy. Here, understanding the market does not refer to understanding economical concepts in the copper market such as supply chain or futures contracts, but rather relationships of different data such as prices, deductions or warehouse stock data.

6.1 Elasticity of copper scrap

One aspect that could provide interesting insight into the copper scrap market is to what extent the copper scrap deductions depend on the LME price level. According to classical microeconomic theory, a rise in prices occurs, when either supply drops or demand rises. In practical terms, prices would rise when refineries and smelters are not able to buy enough copper materials to cover the demand they face. In such a situation refineries and smelters would be seeking material. In consequence, they would increase their buying prices for copper scrap by decreasing the deductions.

In times of oversupply, the opposite should take place. When LME prices are low, which means that current demand is smaller than current supply, smelters and refineries tend to be oversupplied. They would therefore decrease their buying prices by increasing the deductions.

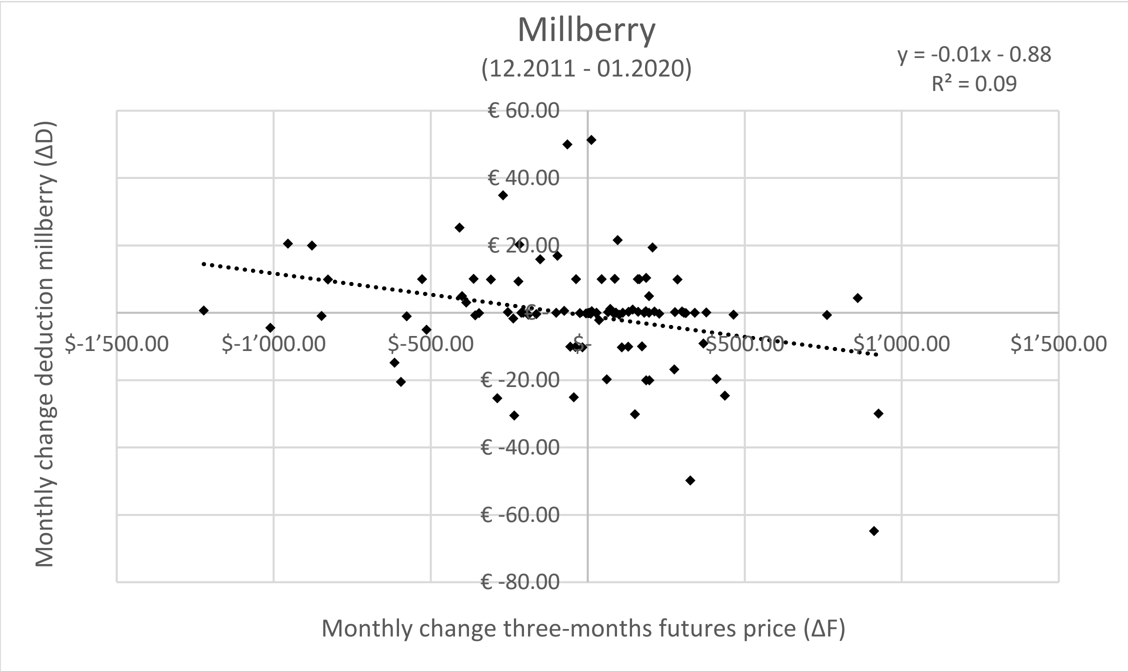
In conclusion, the hypothesis would be that when LME prices are increasing, the deductions for copper scrap are decreasing and when LME-prices are decreasing, the deductions are increasing.

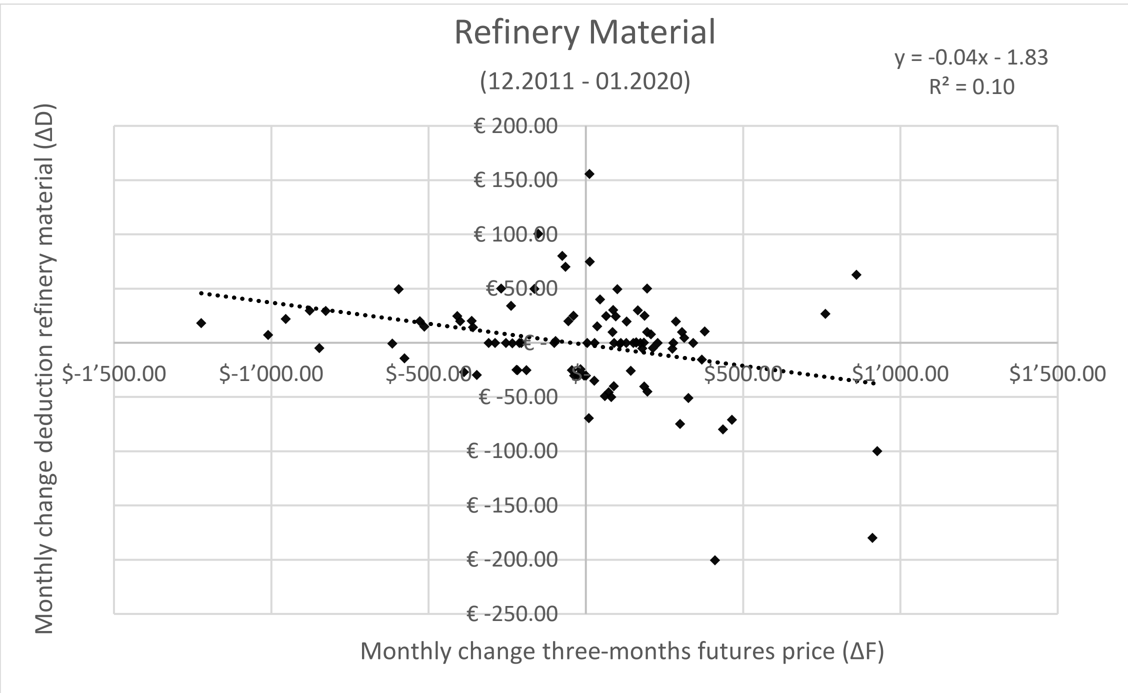
In order to examine the relationship between the deductions and the LME prices, the monthly change in the deduction (ΔD) is regressed on the monthly change in the three-months futures price (ΔF).

$$\beta = \rho_{\Delta D,\Delta F} \frac{\sigma_{\Delta D}}{\sigma_{\Delta F}}$$

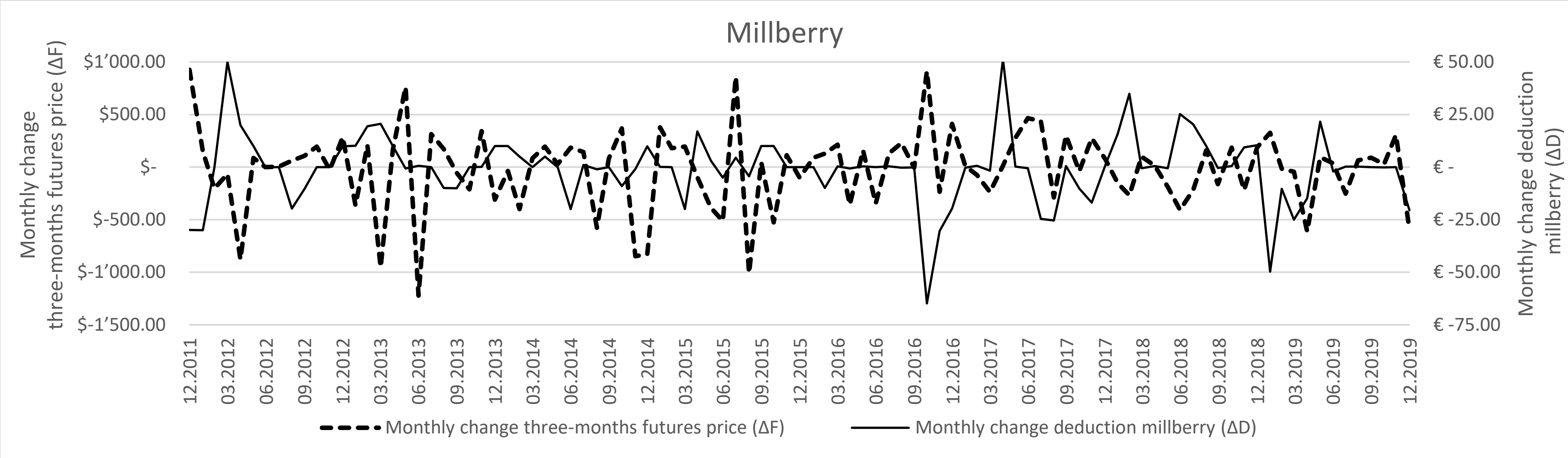
Before going into the results, it needs to be explained, how the deductions are indicated in the data. As the definition of a deduction already outlines, it is an amount that is deducted from a basis price (here from the LME copper price). Therefore, the deduction is indicated as a negative number. This is also the standard in the industry. In terms of terminology, this means that if the deduction "increases", the negative number falls even more into negative numbers. If the deduction decreases, it mathematically increases respectively moves closer to 0.00.

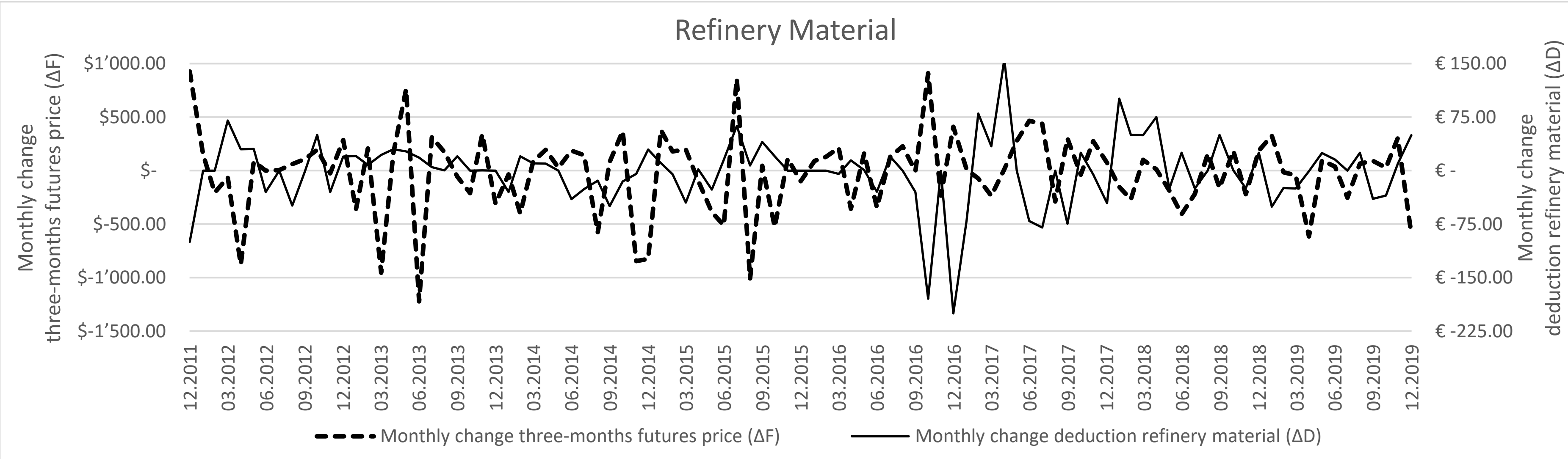
The results of the regression can be shown in the following scatter plots:





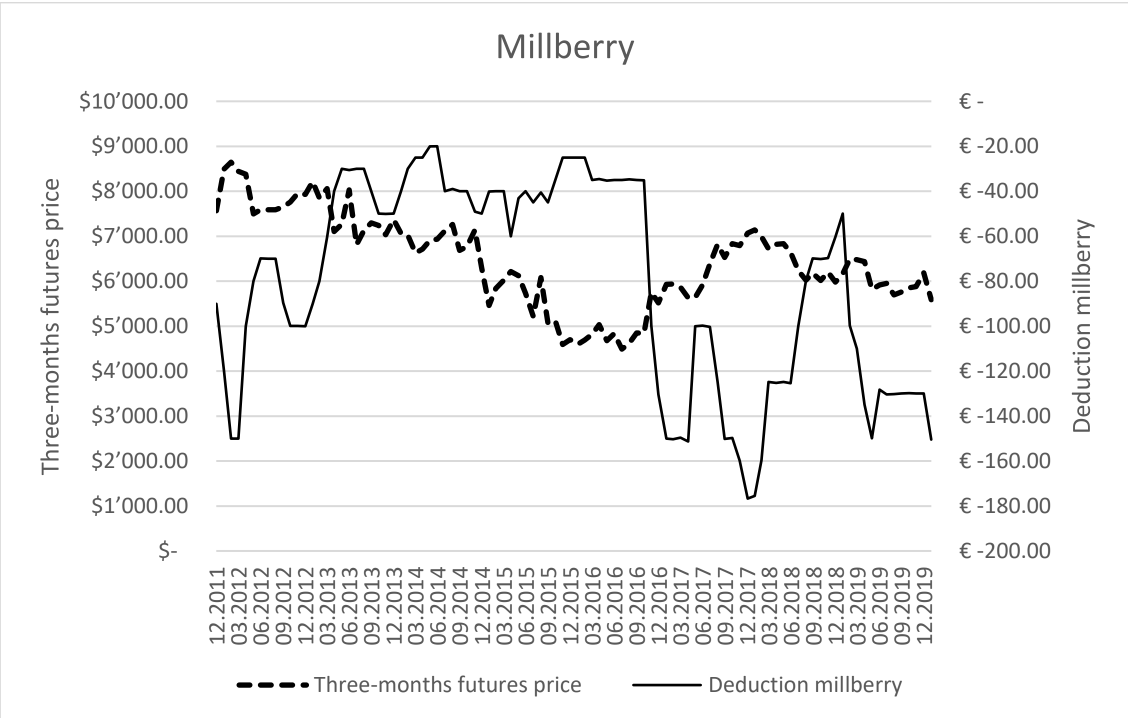
On the following graphs, the change of the individual deductions as well as the change of the LME three-months copper price is outlined in a time series:

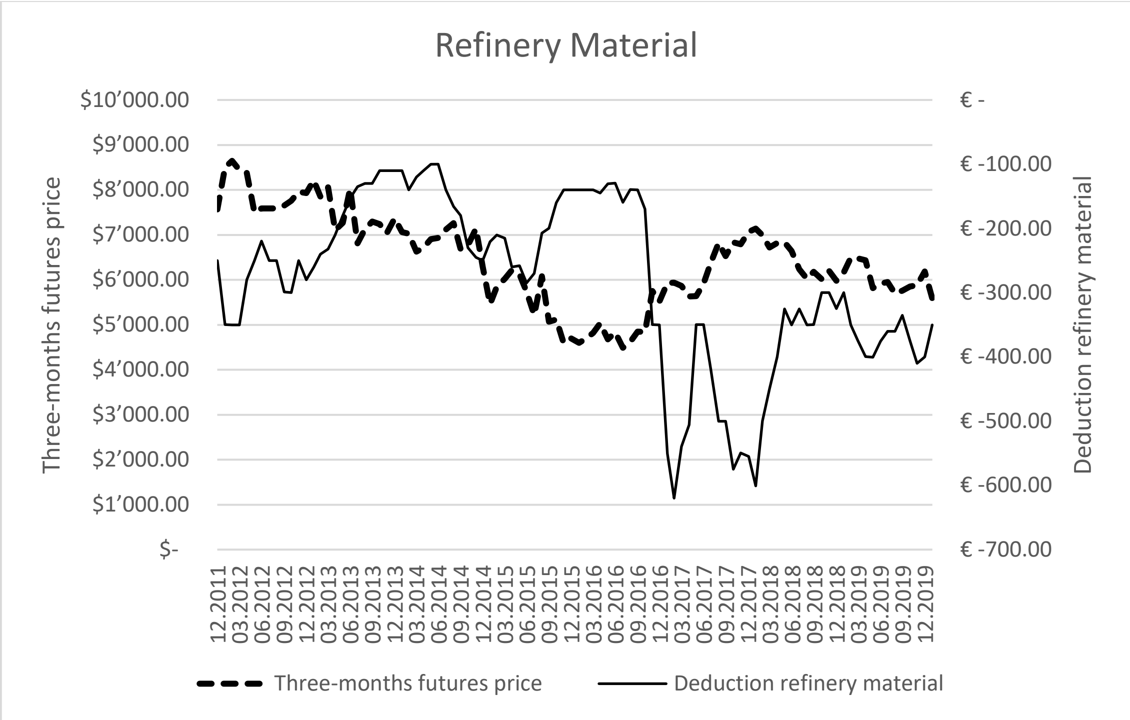




As indicated in the scatterplots, β is negative for both, millberry (-0.01) and refinery material (-0.04). This means, whenever LME prices were increasing (x-axis), the deductions showed a tendency to increase as well (since deductions are negative, this is indicated as becoming more negative). However, in perspective, this does not mean that copper scrap prices decreased in absolute terms. Due to the fact that copper scrap prices depend on the LME, it means that scrap prices would rise proportionally less when LME prices rise. And the opposite would also be true. If LME price falls, copper scrap prices also fall, but proportionally less. In order to translate the above mentioned β into more intuitive numbers, the β of millberry of -0.01 indicates that in average, every time the LME copper price increased by USD 100.00, the deduction changed in average by EUR -1.00. The same comparison can be made with the β of refinery material of -0.04. Every time the LME price increased by USD 100.00, the deduction changed on average by EUR -4.00.

The inversed relationship of the LME copper price and the deduction can also slightly be observed in the time series above, which show the monthly change in the deductions together with the monthly change in the LME three months price. The inversed relationship is however hardly observable in a longer term when the deduction and the LME three-months price are laid over each other directly.





The inversed relationship leads to a rejection of the before set hypothesis. In fact, this research shows that by trend rather the opposite takes place. When prices are high, smelters and refineries would rather encounter a larger supply of copper scrap. They then react by increasing the deductions respectively decreasing the paid copper scrap prices. When prices are low, the supply of copper scrap is also rather low, what makes smelters and refineries increase the prices.

The reason for this could be that scrap yards (suppliers of scrap traders) do often not hedge their positions on a regular basis. They gather smaller quantities on a daily basis and store it. As soon as the prices are high, they will sell their stock in larger lots at once. This might cause an oversupply of copper scrap when LME prices are high. The smelters and refineries must then react by increasing the deductions. In microeconomic terms, the inversed relationship points towards a rather elastic supply, which means that the quantities supplied increase more than linearly to a change in price. However, this explanation can only be true under the condition that scrap yards are willing to bear storage cost in order to receive a better price for their goods.

The inversed relationship between the deductions and the LME copper prices leads also to the fact, that copper scrap prices are slightly less volatile than the LME prices. In a way, this is a further confirmation that the hedge ratio of 1.00 is too high and should be slightly below 1.00.

Nevertheless, the before mentioned conclusions need to be relativized by the calculated R^2. For both materials, the R^2 were at 9-10%. This means, only 10% of the change in copper scrap prices could be explained by a change in LME prices. The remaining 90% were due to other factors that were not included in the calculation. Such factors could be for example changes in electricity or labour cost, which have an impact on production costs and therefore also influence the deductions.

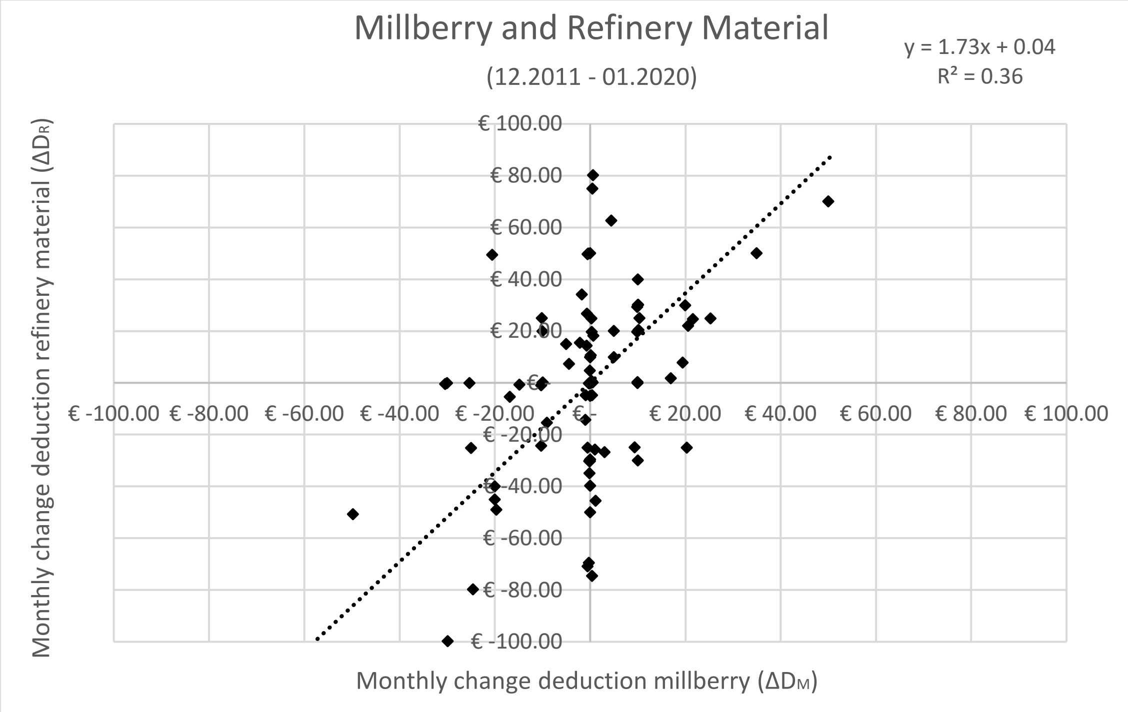
6.2 Dependency of different scrap qualities

Another examined aspect of the scrap market is to what extent the deductions depend on each other. Since not both materials are processed in the same way respectively not in the same step in the supply chain, both materials are traded at different deductions. This can be due to different cost of production of smelters and refineries, but also due to different supply and demand dynamics of each material. If both deductions move symmetrically, this would mean that they depend on the same or similar variables. If they move independent from each other, they do not depend on the same factors. The insight on how both deductions interact might be valuable for a copper scrap trader that works with both materials.

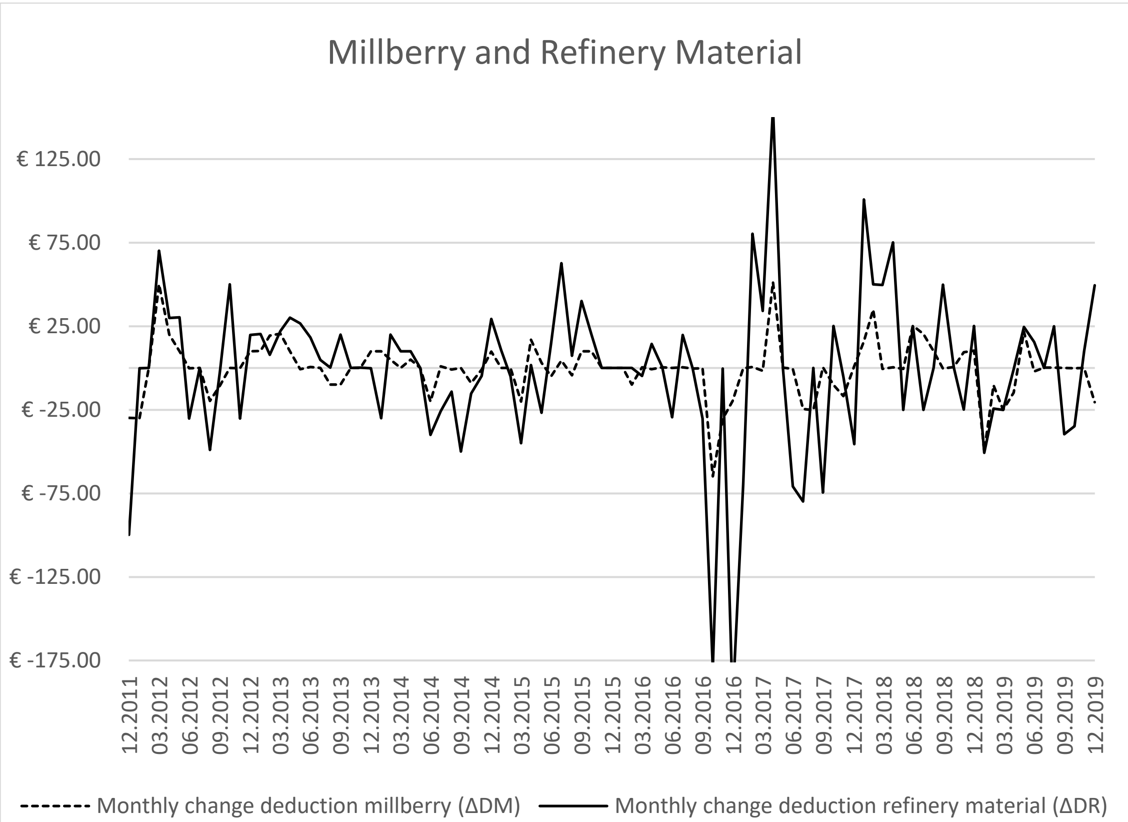
In order to examine the relationship between the deductions, the monthly change in the deduction for refinery material (ΔD_R) is regressed on the monthly change in the deduction for millberry (ΔD_M).

$$\beta = \rho_{\Delta D_R, \Delta D_M} \frac{\sigma_{\Delta D_R}}{\sigma_{\Delta D_M}}$$

The following scatter plot results:



As an extension, the following graph shows the monthly change of the individual deductions in a time series:



As can be observed, both deductions move relatively similar to each other with a β of 1.73. This means, when the deduction for millberry increased by EUR 1.00, the deduction for copper scrap increased by EUR 1.73. This could be explained by the fact that the deductions are to some extent set as a response to the underlying demand and supply situation of copper overall. Since this often influences the entire supply chain, millberry and refinery material would both be affected in similar ways. Overall demand and supply could therefore be an underlying variable that influences both deductions directly, but with different strength.

However, the R^2 of 36% shows that the two deductions only partially are dependent on the same variables. To approximately 64% they depend on variables that do not influence both deductions. As mentioned before, such influence can come from changes in the production cost of the individual materials. For a copper scrap trader, that means that a change in the deduction for one material is not always a reliable sign that the deduction for the other material will change in a similar way.

In connection with these findings, it might be valuable to examine if one deduction reacts on a change of the other deduction with a certain lag period. However, this would go beyond this research's framework.

6.3 Basis vs. deductions

Another aspect that could have an influence on the deduction is the basis of the LME copper market. As already explained before, the basis at the LME copper market is defined as the difference between the cash price and the futures price at a given point in time.

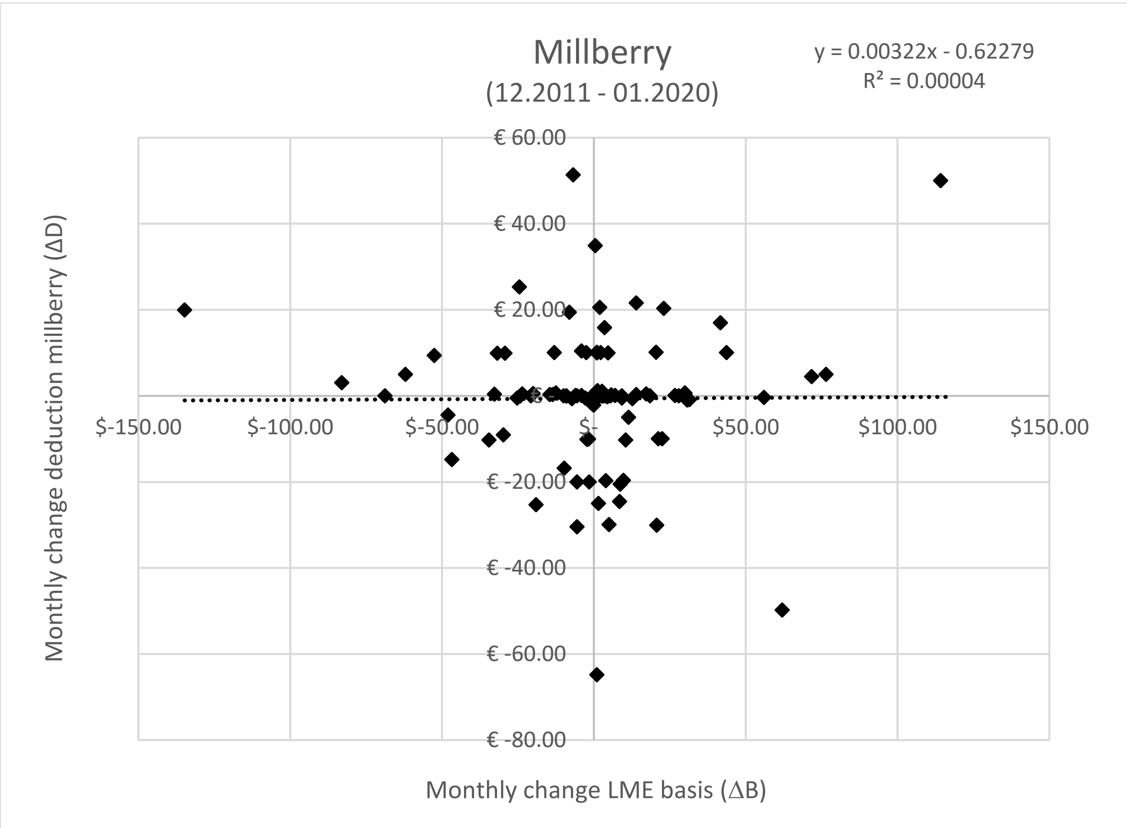
In theory, the LME copper basis consists (amongst others) of two main parts: storage cost and interest. However, also supply and demand can have a considerable impact on the basis. If traders expect an oversupply in the future, the futures price tends to drop, while the cash price would remain stable. Such a scenario would decrease the difference between the two prices and therefore strengthen the basis. Also, if traders experience a short-term oversupply, the cash price might drop while the futures price remains stable. This would increase the difference between the two prices respectively weaken the basis.

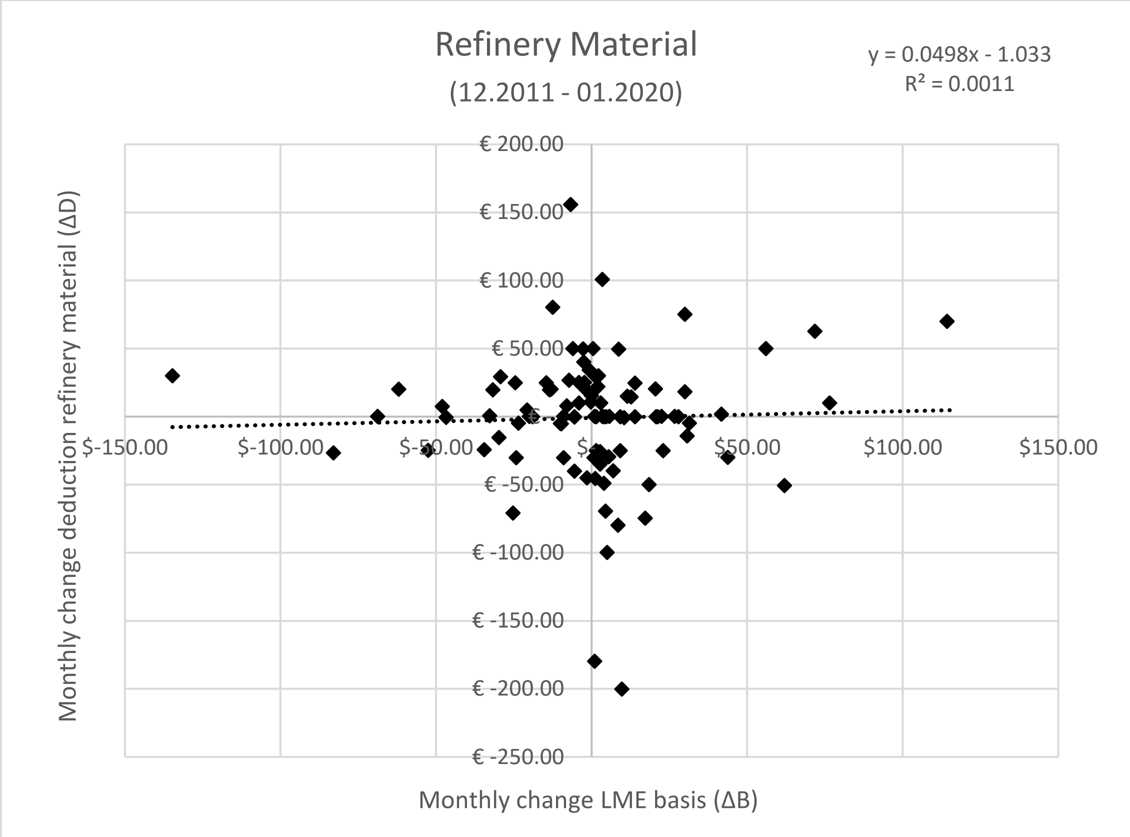
If a change in the basis is caused by changes in supply and demand, it can be hypothesised that a change in the basis goes hand in hand with a change in the deduction. If the market is in contango, respectively the basis is negative and a short-term oversupply causes the cash price to drop, the basis would get weaker (larger negative difference). At the same time, the short-term oversupply might also have an effect on the deduction for copper scrap, causing it to increase and therefore pushing prices down. However, since changes in the basis do not represent an overall change in supply and demand, but rather a short-term indication of change, the effect might be rather weak.

In this research, the basis is calculated by the cash-contract minus the three-months-contract. By regressing the monthly change in the deduction of copper scrap (ΔD) on the monthly change in the basis (ΔB), the relationship between the two can be examined.

$$\beta = \rho_{\Delta D, \Delta B} \frac{\sigma_{\Delta D}}{\sigma_{\Delta B}}$$

The following scatter plots result:





As observable in the two graphs, the relationship between the deductions for copper scrap and the basis on the LME is nearly inexistent. Neither β nor the R^2 of the two materials show a statistically relevant result. Therefore, no direct relationship is indicated. However, the findings that can be taken out of this examination is the fact that the deductions and the basis move independently from each other.

6.4 Stock vs. deductions

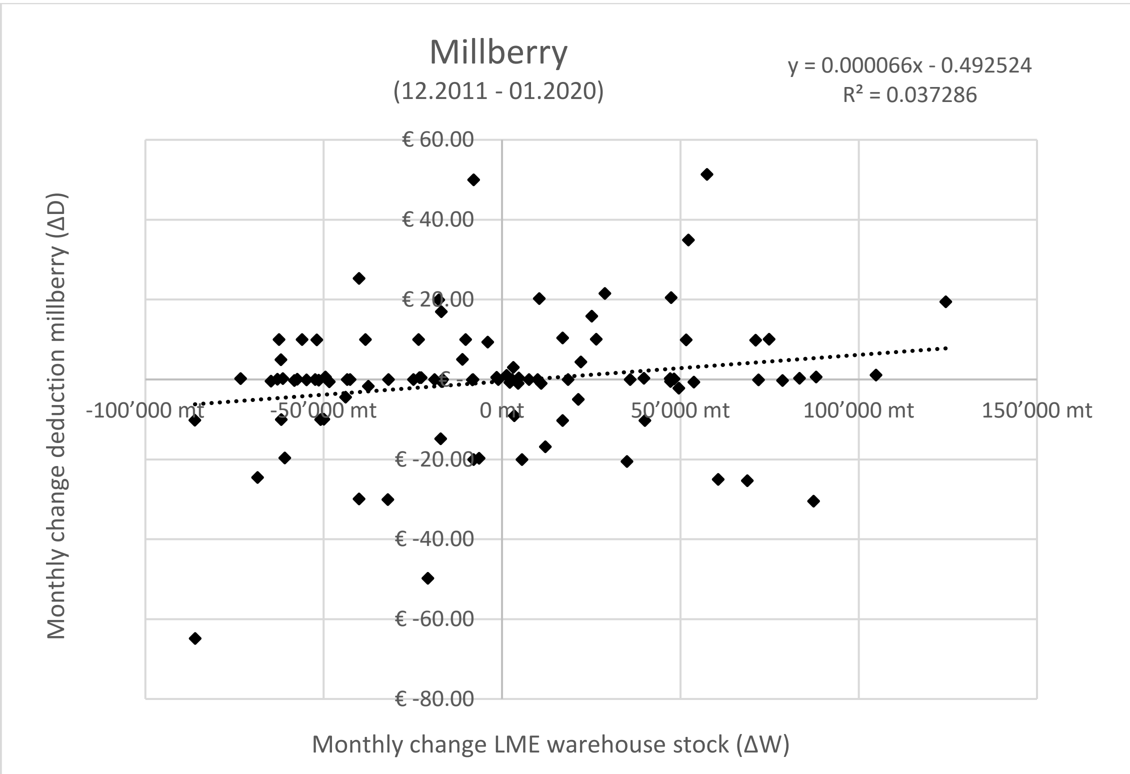
Analogously to the research that has been conducted with regards to the basis, the storage data can be examined. As already explained in the introduction, the LME monitors various warehouses all over the world. Those must report daily, how much copper is stored in their stock. Traders often refer to the stock data as an indicator for over- or undersupply. If refineries cannot find buyers for their cathodes, they will deliver it into a warehouse. They can then sell the warrant that they receive over a futures contract on later dates. The same can happen if the supply of copper cathodes is too low. When manufacturers of semi-fabricated copper products cannot buy copper cathodes directly from refineries, they can turn to the LME and buy a warrant over a futures contract. With the warrant, they can obtain copper cathodes out of an LME monitored warehouse.

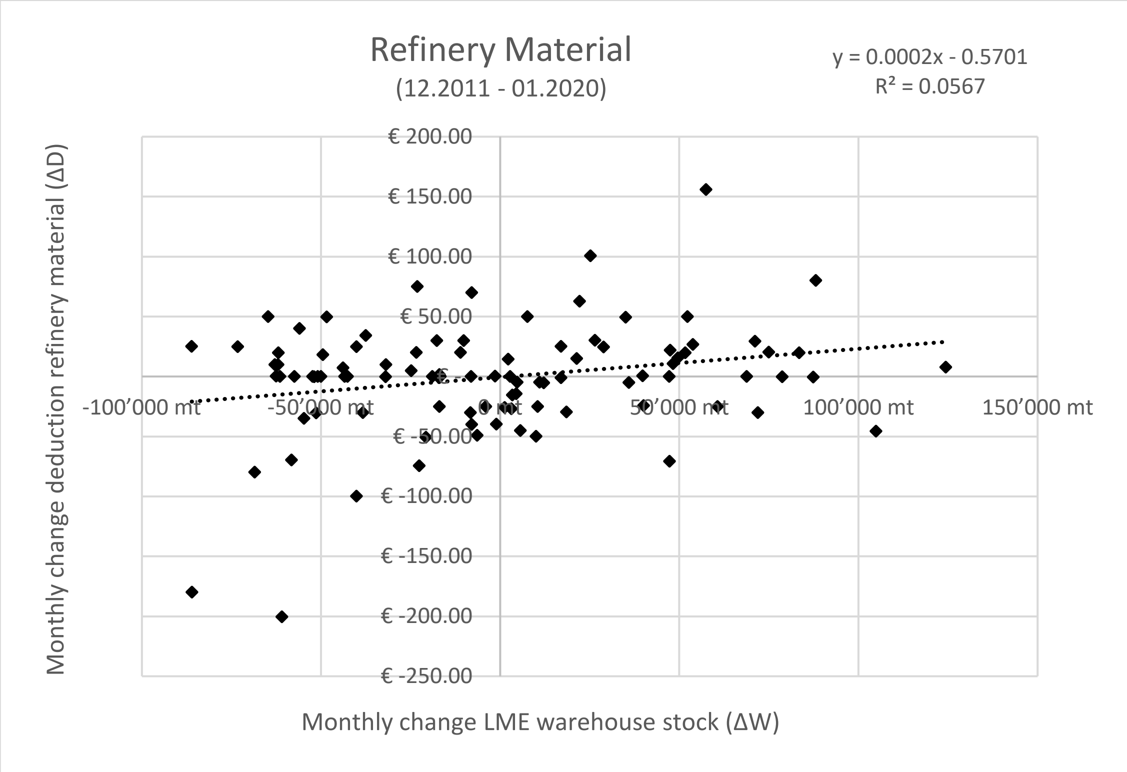
Therefore, the change in the LME warehouse stock could be taken as an indicator for over- or undersupply. If this is the case, it could be expected that if warehouse data increases, supply is larger than demand. In consequence, smelters and refineries would also increase the deductions and therefore decrease the price for copper scrap. If warehouse data is falling, supply is lower than demand and smelters and refineries would decrease the deductions respectively increase the price for copper scrap.

Understanding how the deductions interact with the warehouse data might be useful for scrap traders when predicting possible changes in the deductions. The relationship can be examined by regressing the monthly change in deductions (ΔD) on the monthly change in the warehouse stock (ΔW).

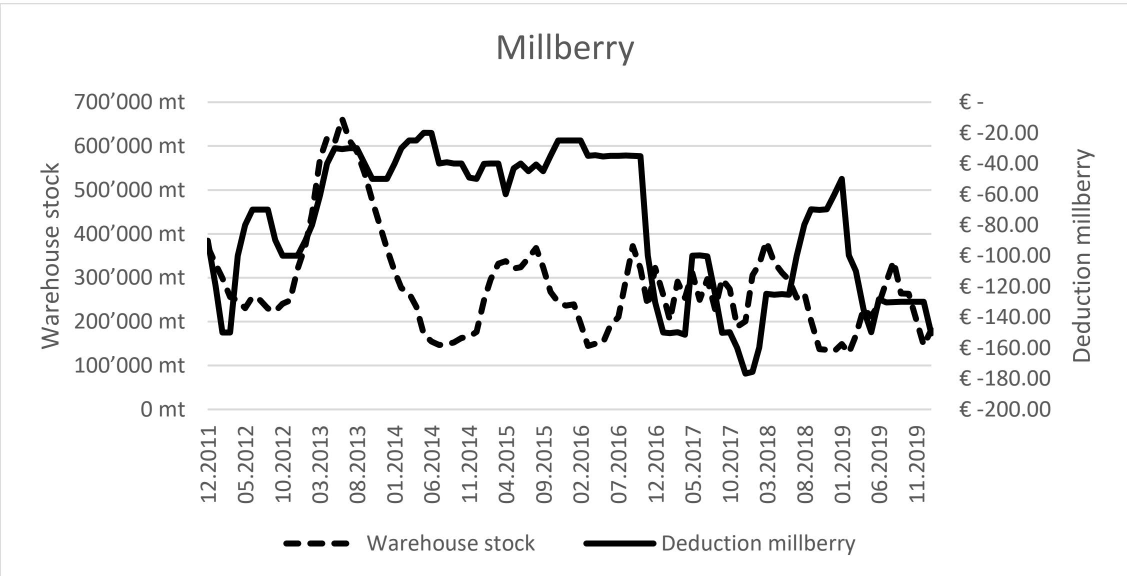
$$\beta = \rho_{\Delta D, \Delta W} \frac{\sigma_{\Delta D}}{\sigma_{\Delta W}}$$

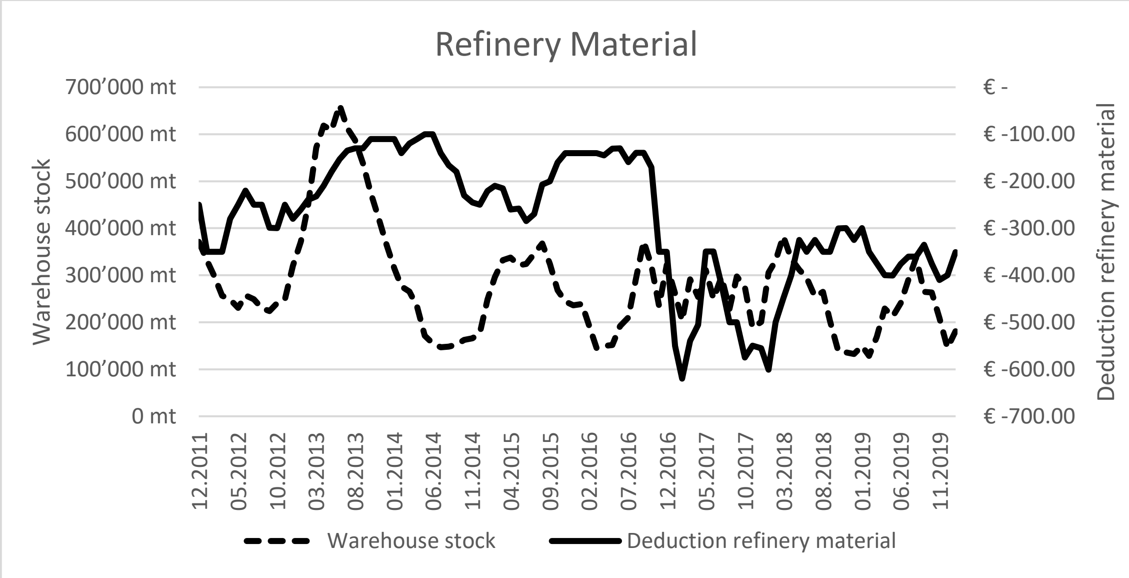
The result of the calculations can be shown in the following scatter plots:





As can be observed, the trendline indicates only a very slight relationship between storage data and copper scrap deductions. Further, the R^2 indicates that only a very small part of the change in the deductions can be explained with the change in the warehouse stock. Also, when lying the warehouse stock and deductions over each other, hardly any reliable pattern can be spotted.





In conclusion, the hypothesis that there is a relationship between changes in warehouse stock data and changes in copper scrap deductions needs to be rejected.

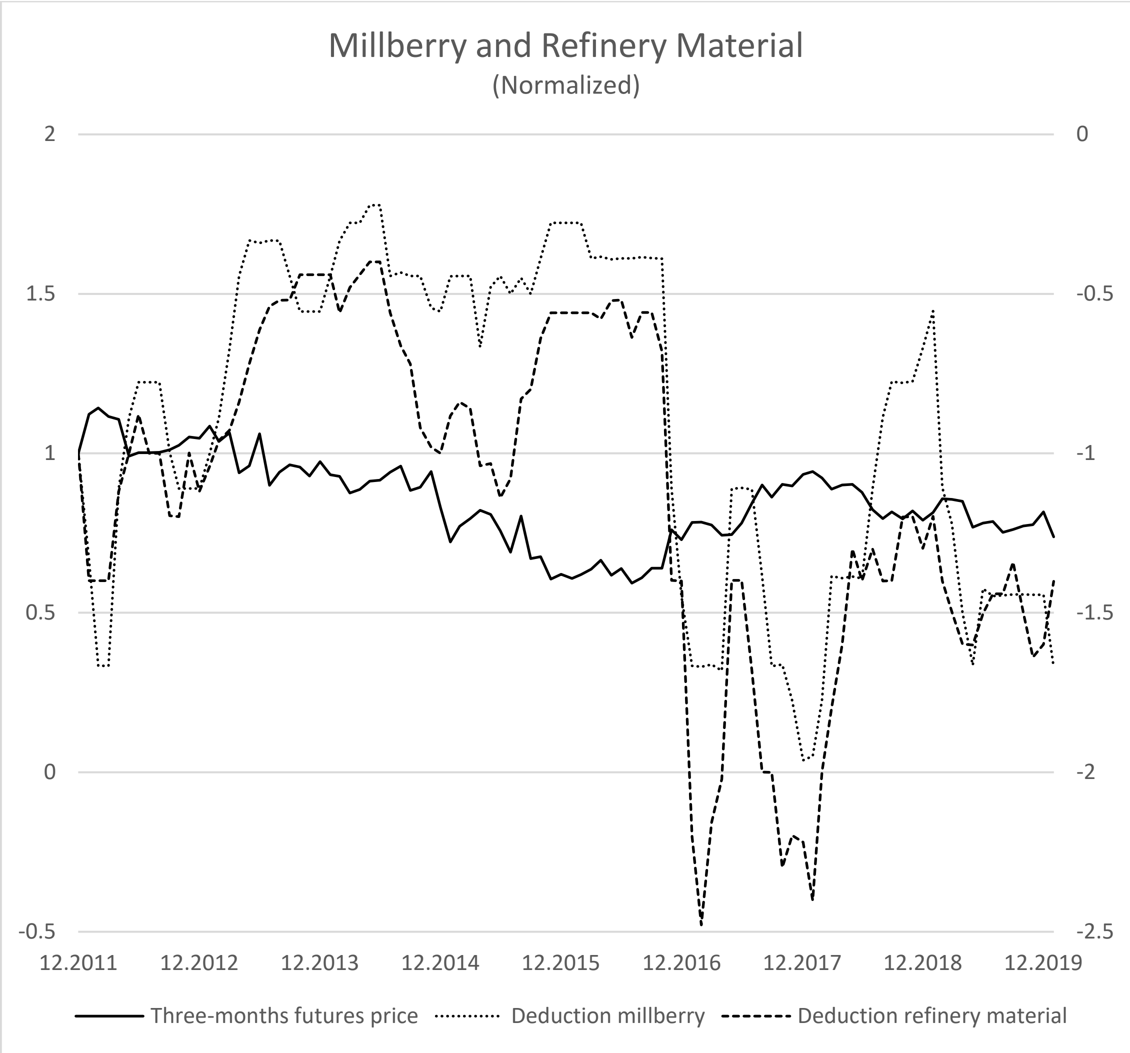
6.5 Substitution

In the last part of this research, it was examined how millberry and refinery material would substitute each other in the supply chain. Although both products are to some extent similar, they are traded at different price levels. This could lead to the hypothesis, that in times of high overall price levels, the cheaper product (refinery material) is preferred. In times of lower price levels, the more expensive premium product is preferred (millberry).

If this hypothesis would hold, the prices for refinery material would rise stronger than the prices for millberry when prices are low. When LME prices are high, the opposite would take place.

Nevertheless, although a variety of different mathematical models has been used for the analysis, such a phenomenon was not discovered. The reason for this might be that the two products are still considerably different and cannot be seen as a full substitute for each other. While refinery material needs to be smelted and refined, millberry can often be used directly in the fabrication of semi-fabricated products by manufacturers. For this reason, it would not be possible to buy more refinery material in order to compensate for overpriced millberry.

The following graph shows both deductions as well as the LME three-months futures price over each other in normalized terms:



7 Conclusion

7.1 Hedge ratios

In this research, a variety of analyses has been conducted. After a prolonged introduction into the copper market and its hedging mechanism, the ideal hedge ratio was examined by means of ordinary least square regression. By regressing the spot price of millberry and refinery material on the copper futures price, it became clear that the naïve hedge ratio of 1.00 would not have been ideal over the time period of the given data (December 2011 to January 2020). The regression showed that the optimal hedge ratio would have been at 0.95 for millberry and 0.88 for refinery material on a hedge horizon of three months. By conducting the same calculation with shorter hedge horizons (two months and one month) it was observable that the hedge ratio is larger respectively closer to one if the hedge horizon is shorter. Even if Dewally & Mariott (2008) as well as Chen, Lee & Shrestha (2003) stated that the hedge ratio will be higher and closer to 1.00 on longer hedge horizons, this is only in very limited ways comparable to this research. While Dewally & Mariott (2008) and Chen, Lee & Shrestha (2003) examined the hedging effectivity of the LME futures markets when hedging the underlying directly, this research examines the hedging effectivity when hedging a product that is only similar to the underlying (cross hedging). This involves the consideration of deductions that are applied to transform the LME prices to specific copper scrap prices.

Since the deductions change over time, additional price fluctuations are created. If the deductions would not change over time, the results of this research would most likely be very similar to the results of Dewally & Mariott (2008) and Chen, Lee & Shrestha (2003). However, the volatility of the deductions needs to be considered when setting up an effective hedge for a physical copper scrap product. Further, since deductions hardly change on short terms but considerably over longer terms, it seems only logical that the optimal hedge ratio deviates stronger from 1.00 over longer hedge horizons, but not so much over shorter hedge horizons.

The above calculation in its nature took the past data and calculated backwards-looking what hedge ratio would have been optimal over the given time period. Although the calculated ratio is very precise, it was only optimal in the past and might change in the future. Nevertheless, it allows for calculating to what minimum the variance of the hedger's portfolio theoretically could have been reduced, if the optimal ratio would have been known. It can further serve as an estimate for the optimal hedge ratio in the future. This strategy can be realistically simulated and tested on its efficiency by means of an out-of-sample test.

In order to create a realistic scenario, out-of-sample tests have been conducted. The out-of-sample test takes a given point in time and calculates the optimal hedge ratio based on prices that would have been known at this point in time and applies it forward-looking as an estimate for the optimal hedge ratio in future hedges. The results showed that by doing so the hedge can be improved, however, depending on the market situation and moment chosen, it can also worsen the performance. This showed that such a stationary hedge is not always reliable.

An examination of the hedge ratios over time has shown that the optimal hedge ratio itself varies considerably. Due to this, it was assumed that a dynamic hedge, in which the hedge ratio is adjusted every time when a new hedge is entered, could lead to a more reliable outperformance of the naïve hedge ratio of 1.00. In four scenarios, four different dynamic hedges with windows of 10, 20, 30 and 40 months were tested. In all four scenarios, the dynamic hedges outperformed the naïve hedge ratio by approximately 8%-11%. This indicates that, when it comes to optimising the hedge ratio, the dynamic hedge would be the more solid alternative compared to the simple stationary hedge as calculated in the out-of-sample test.

Nevertheless, what calculation window would be optimal for hedging would still have to be tested in a statistically significant way. Additionally, the dynamic hedge could also be further improved by weighting the more recent data in the calculation window more heavily than older data. This could lead to hedge ratios that are more up-to-date and therefore also better adjusted to future prices. However, determining whether this would be the case would require additional examinations, which would reach beyond the extent of this research.

Since this research always assumed a hedge horizon of three months, further research about hedging with other hedge horizons could bring additional valuable insights into the copper market and its hedging possibilities. For example, it would be valuable to know which hedge horizon would have led to the largest reduction of price fluctuations. With regards to the dynamic hedge, it might be interesting for copper scrap traders to know if a certain window length leads to a considerable outperformance in comparison with other window lengths.

7.1.1 Limitations

Although the aim of this research was to obtain results that are as applicable as possible, some limitations apply. The calculations for the optimal hedge ratio have been conducted on the assumption, that the hedger targets a hedge horizon of three months. However, physical hedgers cannot always decide on what exact horizon they want to hedge. They are bound to the physical market and can therefore not choose freely, when to buy and when to sell. Further, it needs to be considered that for simplicity reasons, the research has been conducted on the basis of prices per tonne. However, buying or selling individual tonnes of copper futures contracts is not possible on the LME market. One contract always includes lots of 25 tonnes. This can make it difficult for smaller scrap traders to always enter into a hedge with the appropriate amount of copper futures.

7.2 Other determinants

Further in this paper, different determinants of the copper scrap market have been examined. First, the relationship between copper scrap deductions and LME prices has been analysed. The findings have pointed out an inversed relationship between them. In other words, when LME prices increase, the copper scrap deductions tend to increase as well, which causes the scrap prices to increase proportionally less compared to the LME price. When LME prices decrease, copper scrap prices decrease proportionally less, due to the same mechanism. It can therefore be stated that in general, the prices for copper scrap vary simultaneously to the LME copper prices, but usually in a lower range respectively with lower volatility. This would underline the findings of the first part, since in such a situation an optimal hedge ratio below 1.00 can be expected. The reason for this constellation is not thoroughly investigated in this research, but it is expected that smaller scrap yards, that do not apply any hedging for their material, avoid it in general selling at low prices. This would create a tendency for oversupply of copper scrap when prices are high, which leads to larger deductions respectively comparably lower scrap prices when LME price levels are high. When considering this hypothesis, it is important to keep in mind that copper scrap is only one third of the overall supplied copper. Two thirds are supplied in copper concentrates from mines. The copper concentrate supply influences the market in its own way and has due to its size a larger influence on the market.

In order to examine how similar the deductions move with each other, the deduction for refinery material was regressed on the deduction for millberry. It was found that there is a tendency that both deductions move in similar directions, while the deduction for refinery material moves in average 1.7 times the amount of the deduction for millberry. The resulting R^2 of 36%, however, pointed out that only approximately one third of the movement in the deduction for refinery material can be explained by the movement in the deduction for millberry. The other two thirds are due to other variables, that have not been included in this research. Such variables could be changing process costs, that affect one material considerably more than the other. Concrete examples could be the cost for electricity or labour in Europe. Examining these variables could bring additional valuable insight to copper scrap traders in order to predict changes in deductions already at an early stage.

Further, the relationship between the deductions and the basis as well as the warehouse stock data was examined. Although a relationship was expected in both cases, neither of them could be found or proven by the means of ordinary least square regression.

It was also investigated if copper refinery material and millberry could substitute each other in times of considerably above-average or below-average prices. However, such a phenomenon could neither be proven nor found. The reason for this could be that although both products are similar, they cannot substitute each other in the process steps, in which they are physically used.

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