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# Price Discovery, Arbitrage and Hedging in the LME Steel Billet Futures Market

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## Abstract

We investigate the effectiveness of steel billet futures, traded on the London Metal Exchange, as hedging tools for steel manufacturers, consumers and merchants. Particularly, we investigate the magnitude of price divergence risk in using steel billet futures for hedging purposes, in order to ascertain the effectiveness of the futures contract for hedging purposes. We use three analytical tools – price discovery analysis, arbitrage analysis and a case study approach to assess the magnitude of price divergence risk and determine the hedging effectiveness of steel billet futures. We conclude that steel billet futures traded on the London Metal Exchange have significant price divergence risk and thus are ineffective hedging tools for steel manufacturers, consumers and merchants. [1]



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# 1. Introduction

Steel is one of the most important alloys in the world. It is used to make a variety of products that are used in agriculture, construction, healthcare, industry and transportation. There are two types of steel products – flat products and long products. Flat products include plates, hot-rolled strips and sheets, and cold-rolled strips and sheets. These products are used in automotive, heavy machinery, pipes, and tubes, construction, packaging, and appliances. Long products include billets, blooms, re-bars, wire rods, rails and drawn wire. Long products are used in construction, mechanical engineering, and energy industries. Steel products are generally produced from iron ore or steel scrap – recycled steel.

Global steel production has increased by leaps and bounds in the last few decades, from 568 million tons in 1980 to 1548 million tons in 2012[2]. Few decades back, major steel producers were located in First World countries in North America and Europe. However, in the last 20 years, the focus of steel production has shifted to developing countries such as China, India, Brazil and Turkey. Today, steel has emerged as one of the most widely traded commodities in the world, with several countries active in the steel trade, either as net steel importer or exporter.

The global steel industry has historically been a highly cyclical industry. It is strongly linked to expectations of future economic conditions. As a result, steel prices are generally very volatile. High price volatility affects the economic decisions of steel manufacturers, merchants and users in several industries, particularly in automotive and construction industries. Unlike other metals and alloys such as copper, lead and gold, steel is a highly differentiated product. There are several varieties of steel that fall under the flat and long products categories. These varieties differ in chemical composition, dimensions and other parameters. Due to such high[2]

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[2] "Crude Steel Production." *World Steel Association* -. N.p., n.d. Web. 13 May 2013.

variety of steel products, managing steel price risk is a difficult proposition, as each variety has a different market and thus pricing benchmark. But given the sheer size of the industry and the importance of the alloy for business, it was inevitable that a hedging tool be developed to effectively manage steel price risk. Hence, in the last decade, the steel industry witnessed the introduction of several futures contract, to assist the process of steel price risk management. Amidst all the contracts, the one that gained most traction amongst steel users was the steel billet futures contract launched by the London Metal Exchange.

## 1.1 LME Steel Billet Futures Contract

The London Metal Exchange (LME) is the leading global exchange for trading of metals and alloys. In 2008, the LME introduced futures contract for steel billet that could be delivered in two regions – the Mediterranean and the Far East. Steel billet is a semi-finished steel product that is used for making other long steel products such as bars, rods and pipes. In 2010, the two contracts were merged into a single contract. The specifications of the contract are provided in Appendix A. The contract served the following purposes:

- Hedge price volatility: The primary objective of the steel billet futures was to help producers, users and merchants in hedging price volatility of steel products.
- Market of last resort: The users of the contract could use the London Metal Exchange as a market of last resort, and thus sell or buy steel billet whenever it was not possible for them to do so in the physical steel billet market.
- Benchmark pricing: As mentioned earlier, steel is a highly differentiated product, with each variety having its own unique market and pricing mechanism. Hence, it is difficult to obtain a benchmark steel price, given the high variety. The futures price would serve as a benchmark for

all components in the steel supply chain. For example, scrap traders, who deliver scrap for production of steel billet, as well as wire rod manufacturers could use steel billet futures prices to price their products.

- Long term fixed sales price: The steel billet futures was also introduced to enable manufacturers to offer long term fixed sales price for their steel products and thus lock in profit margins.

## 1.2 Historical Performance of the contract

The historical performance of the contract has been analyzed in two ways: how large were the traded volumes and how closely did the futures price track the physical steel billet price in different regions. The summary of the analysis has been presented below:

- Traded Volume: Initially the steel billet futures contract was divided into the Mediterranean and Far East contracts. Volumes in the first few years were not significantly high, as steel users were skeptical of the hedging and benchmarking function of the futures contract. Thus, volumes in the first two years of the contract were not high. However, since the Mediterranean and Far East contracts were merged into a single steel billet futures contract in 2010, traded volumes increased, reflecting the growing popularity of the LME steel billet futures contract. During this period, the number of participants in the steel billet futures market increased significantly and major banks such as the Deutsche Bank used the contract significantly. However, in the last couple of years traded volume has decreased significantly. The declining trend in traded volumes is shown in the Figure 1. The data for Figure 1 excluded traded volume on July 31st, 2012 where the number of contracts traded was 660. This observation was in stark contrast to the significantly lower volumes observed on days before and after this date. Thus, to show the clear declining trend, this observation has been excluded in Figure 1.

- Tracking physical steel billet markets: The price of the futures contract of any commodity should be closely interlinked with the price of the physical commodity in different regions. If the futures and physical market prices diverge, then it implies inefficiency in pricing of the commodity in either market. In Figure 2, the price of LME 3-month steel billet futures has been shown against the price of Black Sea Export FOB billet and East Asia Import Billet CFR. These two billet benchmark prices are important as the Black Sea and East Asia regions are the largest trading hubs of steel billet in the world. Please note that the terms FOB and CFR, along with export and import billet are not important in our discussion. There is difference in the absolute values of all three prices, due to the difference in steel billet prices in different regions. We notice that the gap between the LME steel billet price graph and the other two billet prices graphs is insignificant in the first few years of the futures contract. This indicates that the steel billet futures price was an excellent benchmark of global steel billet, since most of the steel billet trade is centered in the Black Sea and East Asia regions. However, the gap increases in the last two years of the contract. This indicates that in the last two years, the steel billet futures price has not closely tracked the price of steel billet in major physical markets. Thus, the benchmarking ability of steel futures contracts has declined in the last two years.

## 1.3 Concerns about the hedging performance of steel billet futures

The history of the LME steel billet futures contract suggests that the contract gained popularity in the initial years. However, major steel producers and merchants have resisted using the contract since its inception. In fact, the contract's popularity has declined in the last few years, as implied by the fall in traded volumes. The fact that traded volumes declined in the last two years, even though steel production recovered since the financial crisis of 2008-09, raises the question of the effectiveness of the contract and its hedging benefits. Moreover, doubts about the hedging function of the contract are further enhanced by the divergence between the steel billet futures prices and the physical billet prices in the last two years.

This paper will attempt to resolve the question around the effectiveness of LME steel billet futures as a hedging tool. The question can be answered by analyzing the magnitude of price divergence risk in using the futures contract. Price divergence risk is the risk to the hedger due to divergence of price movements in the futures and spot billet markets. For example, suppose a steel merchant owns a steel billet and uses a short steel billet futures position to hedge against any fall in billet prices. In this case, the steel merchant would prefer that when the price of spot billet drops, causing him a loss on his long spot billet position, the short billet futures will offset the losses since the short futures position will become profitable when prices of the billet drop. However, this is true as long as futures and spot billet prices follow similar paths i.e. when spot billet prices drop, billet futures prices also drop. But what if the futures and spot billet prices follow different paths? In that case the short futures position may not always offset the loss on the long spot billet position. In that case, the futures contract, instead of lowering losses ends up accentuating losses for the user of the contract. This risk of the futures and spot billet prices diverging is defined as price divergence risk. Hedgers want price divergence risk to be as low as possible, in order to induce them to use futures as a hedging tool. In the presence of significant price divergence risk, the futures contract becomes an ineffective hedging tool. Thus the question of whether LME steel billet futures are effective hedging tools or not can be answered by analyzing price divergence risk.

To assess the magnitude of price divergence risk, I will use three methods – price discovery analysis, arbitrage analysis and case study. The price discovery analysis will focus on analyzing whether prices are discovered simultaneously in futures and spot billet markets, and whether the rate of convergence of prices in both markets is high or not. The arbitrage analysis will focus on whether arbitrage opportunities with respect to spot and futures billet persist for long periods. The case study will analyze the structural reasons behind the billet futures market not perfectly tracking the important physical billet markets. Using all three methods, we will be able to determine the magnitude of price divergence risk in using the futures contract for hedging purposes. Thereafter, we shall be able to determine whether LME steel billet futures are effective hedging tools or not.

## 2. Price Discovery Analysis

The price discovery analysis entails analysis of the price discovery process in the futures market and the correlation between price changes in the futures and cash markets. The analysis of price discovery will help us determine which of the two markets is dominant over the other in terms of flow of information. Perfect and complete flow of information between the two markets ensures that prices in both markets always move in synchronization. Analysis of price discovery also presents us with information of elasticity of supply of arbitrage services, a measure that will be defined in the next section. The elasticity of supply of arbitrage services, along with price discovery analysis helps make inferences about the price divergence risk in using the futures contract for hedging.

In order to understand the price discovery process between the two markets, a model proposed by Kenneth D. Garbade and William L. Silber[3] has been used. The model relies on empirical estimation of a quantity called elasticity of supply of arbitrage services, which helps explain the relationship between the futures and cash markets, and make inferences about the hedging performance of the futures contract.

## 2.1 Methodology - Overview

The basic tenets of Garbade and Silber's model indicate that the price discovery process in futures markets is related to the hedging or risk transfer function of the futures contract. Price discovery is a concept that refers to the process of determination of prices in the futures market, relative to price determination in the cash market. Garbade and Silber suggest that when new information about the underlying commodity becomes available to participants in both markets simultaneously, prices will be determined in both markets simultaneously. In that case, both markets will be completely integrated and the futures contract will be a very effective hedging tool for contract users. This is because of the fact that complete market integration prevents the creation of any risk associated with price divergence between the two markets. In the absence of such price divergence risk, the futures contract can be used effectively by the hedger.

If new information becomes available to one market first, and then to the other market after significant lapse, then the price determination process in both markets will not be in synchronization. In this case, the market where new information becomes available first, dominates over the other market, in the sense that prices in the former facilitate the prices in the [3]latter. The markets in this case are not perfectly integrated, and thus the futures contract may not be used effectively as a hedging tool. Thus, the discussion of price divergence risk boils down to

[3] Garbade, D. Kenneth and Silber, William. "Price Movements and Price Discovery in Futures and Cash Markets". *The Review of Economics and Statistics.* Web. 02 May 2013.

the analysis of the price discovery and market integration processes between the two markets. Observations of price discovery and market integration will help make inferences about the price divergence risk of using the futures contract. Garbade and Silber explicitly lay down a framework to analyze the price discovery process, and thus the price divergence risk. The framework focuses on the measurement of a quantity called elasticity of supply of arbitrage services and market relationship parameter:

- Elasticity of arbitrage services:

The elasticity of supply of arbitrage services is a measure of the rate of convergence of cash and futures prices. Garbade and Silber postulate that if elasticity of supply of arbitrage services is zero then the futures market is a poor substitute for the cash market position. Prices in both markets follow uncoupled random walks and the futures markets' risk transfer and price discovery functions are eliminated. The futures contract is thus an ineffective hedging tool for the hedger as price divergence risk is high. On the other hand, if elasticity of arbitrage services is infinite, then futures contract is a perfect substitute for the cash market position. In this case, prices are discovered simultaneously in both markets and the futures contract serves as a perfect hedging tool since price divergence risk is low. For non-zero and non-infinite values of elasticity, the two markets follow an intertwined random walk, with one market dominant over the other in terms of price determination. In this case, the futures contract can be used to hedge but the hedge will not be perfect due to price divergence risk.

- Market relationship parameter:

Garbade and Silber also suggest the estimation of a market relationship parameter. This parameter directly measures the relationship between the futures and cash markets, and suggests which market dominates the other. If this parameter is zero then the futures market is influenced completely by the cash market. If the parameter is one then the cash market is influenced completely by the futures market. Intermediate values indicate mutual adjustments and feedback effects between the two markets. The measurement of this parameter also helps make inferences about integration of the two markets and thus the price divergence risk of using the futures contract.

To sum up Garbade and Silber's model, there is a relationship between the rate of convergence of prices in futures and cash markets and the price divergence risk of using the futures contract. At the same time, the relationship between futures and cash market price determination processes also helps make inferences about the price divergence risk. Thus, in the first stage of the three-step analysis, we will understand price discovery in the LME Steel Billet futures contract. To understand price discovery, it suffices to implement Garbade and Silber's model of empirical estimation of elasticity of supply of arbitrage services and the market relationship parameter.

## 2.2 Notation

The inputs to Garbade and Silber's model of price discovery are shown in below:

| | |
|---|---|
| | Natural logarithm of the cash market price of LME steel billet in period k |
| | Natural logarithm of current price of LME steel billet futures for settlement in 3 months in period k |
| | Natural logarithm of cash equivalent LME steel billet futures price in period k |
| | 90-day Certificate of Deposit (CD) rate |
| | Number of days to first delivery |

## 2.3 Equations

The requisite equations that help determine elasticity of arbitrage services and the market relationship parameters are shown below. The equations use the cash equivalent price as an input and the equation for cash equivalent price is also shown below:

| | |
|---|---|
| Cash equivalent price and settlement price equation | |
| Market relationship parameter equations | |
| Elasticity of supply of arbitrage services equation | |

## 2.4 Data:

The prices of cash steel billet and LME steel futures billet were obtained from Steel Business Briefing Limited. Steel Business Briefing Limited is a London based company that provides information products related to steel and steel users. Data for the 90 day Commercial Deposit rate was obtained from Bloomberg. In all calculations the value of was taken as 3 months or 90 days since steel billet can be physically delivered against the contract on any day in the 3 months from the date of purchase of futures contract.

## 2.5 Required Parameters and Method of Estimation:

According to Garbade and Silber's model, the market relationship parameter can be estimated by the value of . If is 1 then cash market prices always move towards futures prices. If the ratio is zero then futures prices always move towards cash prices. For elasticity of arbitrage, Garbade and Silber postulate that estimation of provides a direct measure of the elasticity of supply of arbitrage services. Thus, higher values of indicate higher elasticity of supply of arbitrage services.

Thus, the parameters that we need to estimate are , and . Using price data of LME spot billet and 3-month steel billet futures from 24/07/2008 to 14/09/2012, we estimate these parameters by using linear regression on the market relationship parameter and elasticity of arbitrage equations.

## 2.6 Results – Market Relationship Parameter:

The linear regression results for the market relationship parameter are shown in Table 1. We accept the estimates to be valid, given the statistically significant values of the F-statistic, t-statistic and p-value. Moreover, the standard error is low for both parameters. Garbade and Silber's model postulates that cannot be less than zero. Since is slightly negative, but close to zero, we can safely assume it to be zero, given the low t-statistic at 95% confidence level. Thus, the value of the ratio is 1 in this case since is approximately zero. Thus, in the LME steel billet futures market, prices of spot billet always converge towards futures prices.

## 2.7 Results – Elasticity of arbitrage services

For the value of we used linear regression on the elasticity of arbitrage services equation with the lag period as 1, 10, 20, 30 and 60 days. The lag period here refers to the difference between the period of the prices on the left hand side of equation, and the period of the prices on the right hand side of the same equation. In other words, the lag period is the value of the subscript . The reason we conducted the analysis for with different lag periods, is to understand how and the elasticity of arbitrage changes over time. We wanted to understand how the hedging performance of the billet futures is affected by the length of the hedging period. The elasticity of arbitrage services equation mentioned under the Equations section is for lag period 1. The results for each lag period are presented below and summarized in Table 2 and Figure 3:

### 2.7.1 Lag period – 1 day:

The requisite equation for lag period of 1 day is:

After conducting linear regression on the aforesaid equation, we estimated the value of to be approximately 0.96. The result is valid as we got statistically significant values of all regression parameters. The value of the F-statistic was 12963, which is significantly large. The value of the t-statistic was 114 which is significantly larger than 1.98, for 95% confidence. The measure of p-value was 0 which is less than 0.05.

The high value of for lag period of 1 day indicates that elasticity of arbitrage services is very high. Prices in the cash and futures steel billet markets converge very quickly over short intervals. High value of indicates that the two markets are highly integrated over very short periods. Hedgers using the contract for 1 day will hence not be at significant risk, as price divergence between the futures and cash billet markets is highly unlikely. Thus, the hedging performance of the futures contract is highly enhanced in this scenario.

### 2.7.2 Lag period – 10 days:

The requisite equation for lag period of 10 days is:

The linear regression for the above equation yielded the value of  to be approximately 0.72. The result was statistically significant, with F-statistic at 1259, t-statistic at 35, and p-value at 0. We notice that over a ten day period  falls significantly and thus the elasticity of arbitrage services declines a lot. The futures and cash billet markets are not completely integrated in this situation. Price divergence between the two markets is likely, and thus hedgers are at risk. Thus, the hedging performance of the futures contract declines significantly in a period of 10 days.

### 2.7.3 Lag period – 20 days:

The requisite equation for lag period of 20 days is:

The value for  was approximately 0.56 as per the linear regression on the above equation. We obtained the following values for the F-statistic, t-statistic and p-value respectively: 560, 24 and 0. For a time interval of 20 days, the value of  suggests that integration between the futures and cash billet markets is weaker than in the previous two cases. Elasticity of supply of arbitrage services is still low, indicating that the process of price convergence is slow. Slow price convergence can prevent simultaneous price discovery in both markets, and thus the two markets may appear out of synchronization sometimes. Hence, price divergence risk is higher than in the previous case. Thus, hedging performance of the futures contract declines gradually as the hedging period increases from 10 days to 20 days.

### 2.7.4 Lag period – 30 days:

The requisite equation for lag period of 30 days is:

Linear regression on the lag period of 30 days equation yields a value of 0.45 for . The summary statistics are presented in Table 2 below. The elasticity of arbitrage services does not decrease a lot as we increase period to 30 days from 20 days. Rate of convergence of prices in cash and futures steel billet markets is still low. Market integration is weaker, and price divergence risk is higher than in all previous cases. Hedging performance of the futures contract is worse than in all previous cases, as the hedger faces risk due to imperfect integration between the cash and steel billet markets.

### 2.7.5 Lag period – 60 days:

The requisite equation for lag period of 60 days is:

After conducting linear regression on the above equation, we found the value of to be 0.12. The summary statistics are presented in Table 2. The elasticity of arbitrage services decreases significantly as we change the lag period from 30 days to 60 days. Convergence of prices in the two markets is very slow over long periods. Thus, the low value of indicates that the futures and cash steel billet markets are not integrated over long periods. Due to absence of integration over long periods, risk of divergence of prices in the two markets is high over long periods. Thus, the hedging performance of the billet futures contract declines significantly over long periods.

By observing Table 2 and Figure 3, we notice that higher values of  for small lag periods indicate that elasticity of supply of arbitrage services is high in the very short run. Over longer periods, elasticity of supply of arbitrage services declines. Three inferences can thus be made. Firstly, in the short run, the futures and cash markets are highly integrated, but in longer periods they become less integrated, with cash markets moving towards futures prices. Secondly, over longer periods, price divergence risk increases significantly, as rate of convergence of prices in futures and cash billet markets declines. Thirdly, since price divergence risk is related to the hedging performance of LME steel billet futures, it is clear that with significant price divergence risk, the hedging performance of LME steel billet futures is severely restricted.

To better understand how steel billet futures fares in terms of hedging performance, the values of  for lag periods 1 to 30 days are shown for six other commodities: copper, aluminum, gold, silver, tin and zinc in Table 3. These results are also presented graphically in Figure 4. From Table 3, we observe that all commodities have similar elasticity of supply of arbitrage services for lag period of 1 day. As lag period increases, aluminum and gold separate from the others as these two have the highest elasticity of supply of arbitrage services. For high lag periods, copper and steel billet have the lowest elasticity of supply of arbitrage services. Thus, for small intervals, price convergence is fast for all commodities mentioned here. Hedging performance in this small interval is enhanced as price divergence risk is low. As period length increases, price convergence for steel billet takes place at a slower rate relative to other commodity futures, except for copper. Thus, price divergence risk for long time periods is higher for steel billet than other commodity futures contracts, except for copper. As a result, hedging performance of steel billet futures is worse than other metal futures.

### 2.8 Summary of Price Discovery Analysis:

Using Garbade and Silber's model, we found that the process of price determination in the futures and cash steel billet markets is not simultaneous, with the futures market dominating the cash billet market in this process. We also found that the rate of convergence of prices is low over long periods and low relative to other metals, and this results in low integration between the futures and cash billet markets over long periods. This implies that it is highly likely that futures and spot billet prices can diverge over long periods, creating significant price divergence risk for hedgers. Thus, theoretically, Garbade and Silber's model suggests that LME steel billet futures' hedging performance is severely limited due to significant price divergence risk.

## 3. Arbitrage Analysis

Arbitrage refers to a transaction, wherein you enter into two positions simultaneously, with one position in the futures market and the other in the cash market. One of the positions is a buy or long position on the commodity, while the other is a short or sell position on the commodity. The arbitrage transaction should yield a riskless profit to the arbitrageur. Arbitrage transactions take place due to pricing differences in the futures and spot markets. If arbitrageurs can quickly exploit the arbitrage opportunity, then the pricing differences in the market will be corrected. If the arbitrageurs cannot exploit the arbitrage opportunities then the arbitrage opportunities persist for some time. If they persist long enough, then it implies that the pricing differences are persisting for prolonged period and the two markets are inefficient. Thus, in this case futures and spot prices may be following different paths thereby creating price divergence risk. To sum it up, we need conduct an in-depth analysis of the possibility of arbitrage between LME Steel Billet 3-month futures contract and LME Cash Steel Billet. If arbitrage possibilities exist, then the futures and cash billet markets are inefficient, and thus price divergence risk is high.

We will now investigate the possibility of arbitrage between the cash and futures steel billet markets using a two-step procedure. Firstly, we will look through the steel billet price data from 4/08/2008 to 14/09/2012, and look whether arbitrage opportunities persist for long periods or not. This is crucial in understanding whether arbitrage opportunities exist between the futures and cash steel billet markets and whether they create price divergence risk or not. Secondly, we will assess whether arbitrage is economically feasible or not. In other words, we will try three different strategies – cash and carry arbitrage, short-selling arbitrage and a combination of both, from 4/08/2008 to 14/09/2012 to understand whether arbitrage is economically feasible or not. This is important to understand whether the arbitrage profits are significantly large to induce arbitrageurs. Low arbitrage profits will not lure arbitrageurs to exploit the arbitrage opportunity. Thus, if arbitrage opportunities persist for long periods and arbitrage profits are high, arbitrageurs will be tempted to exploit those opportunities. However, they may not be able to exploit them, in spite of the large profits that they could earn, and thus price divergence risk may be created as pricing differences persist. After implementing the two-step procedure to understanding arbitrage, we will be able to understand whether futures and cash billet markets are efficient or not, and thus we will be able to strengthen our inferences on price divergence risk using Garbade and Silber.

## 3.1 Existence of arbitrage opportunities

There are two possible arbitrage strategies that arbitrageurs can use. The first arbitrage strategy is the cash and carry arbitrage strategy. Under this strategy, the spot steel billet looks cheaper compared to the futures steel billet. Thus, the arbitrageur will buy spot steel billet, and short the steel billet futures simultaneously. The arbitrageur will then carry the long spot position till expiration, incur all costs associated with the position, such as storage costs. On expiration, the arbitrageur will deliver the billet against the short steel billet futures position, and earn the arbitrage profit minus costs of carrying the billet position.

The second arbitrage strategy is the opposite of the first one. Here, the spot steel billet looks expensive compared to the futures steel billet. Thus, the arbitrageur will buy the steel billet futures, and short sell the spot billet. After short-selling the spot billet, the arbitrageur can invest the short sale proceeds and earn interest till the period of expiration of the futures contract. On expiration, the arbitrageur will take delivery of the steel billet against the long steel billet futures position, and then will deliver the billet to the institution from where the arbitrageur borrowed billet for short selling. However, short-selling arbitrage is more difficult to implement than cash and carry arbitrage. There are two reasons why short-selling may prove a difficult proposition. Firstly, it may be difficult to find institutions or steel companies that will provide the requisite steel billet, conforming to the standards of LME. Secondly, there is the issue of convenience yield which deters steel companies possessing the steel billet from using their billet to perform short-selling arbitrage. Convenience yield is the benefit associated with holding the steel billet, instead of short-selling it for arbitrage purposes. The benefit may arise due to scarcity of the steel billet or other factors.

For the purpose of our analysis, we will investigate both strategies, each under two cases. For cash and carry arbitrage, we will first investigate arbitrage assuming no storage costs and then taking storage costs into consideration. For short-selling arbitrage, we will first investigate arbitrage assuming no convenience yield and then taking the same into consideration.

### 3.1.1 Assumptions

The arbitrage calculations were conducted after making the following assumptions:

1. 3 month LIBOR was considered as the risk free interest rate
2. Storage costs estimates were taken from information available on the website of Henry Bath, which has warehouses for steel billet and several LME traded commodities. The estimates are for year 2012.
3. For years earlier than 2012, historical Euro-zone inflation numbers were used to extrapolate storage costs. For more information on storage costs, see Appendix B.
4. For simplicity, storage costs are the only assumed costs of carrying a long steel billet position. Transportation costs and other costs are ignored.
5. Convenience yield was calculated using a model established by Rajna Gibson and Eduardo S. Schwartz[4]. For more details of the calculation of convenience yield, see Appendix C.
6. Continuous compounding has been assumed for accrual of interest.
7. The equations for both arbitrage strategies have been determined using the no-arbitrage futures pricing equation mentioned by John C. Hull. [5]

### 3.1.2 Notation

The various inputs to the no-arbitrage pricing equation and its variants are provided in below:[4]

| | |
|---|---|
| | Bid price of Spot/Cash steel billet |
| | Ask price of Spot/Cash steel billet |
| | Bid price of one 3-month LME steel billet future |
| | Ask price of one 3-month LME steel billet future |
| | Annualized 3 – month LIBOR rate |
| | Storage costs |
| | Convenience yield |

### 3.1.3 Cash and Carry Arbitrage – without storage costs:

Using Hull's no arbitrage futures pricing equation, we derive that the equation related to cash and carry arbitrage is: . As long as this equation holds arbitrage will not take place. But when , steel billet futures seem overpriced relative to spot steel billet. Arbitrageurs will thus buy spot billet, short billet futures and hold both positions till expiration.

[4] Gibson, Rajna and Schwartz, Eduardo. "Stochastic Convenience Yield of Oil Contingent Claims". *The Journal of Finance.* Web. 02 May 2013.

[5] Hull, John. "Options, Futures and Other Derivatives". Web. 02 May 2013.

We tested this inequality for all daily observations in the given price data sample. Out of 948 daily observations, there were 271 days when cash and carry arbitrage without storage costs could take place. The results are summarized in Figure 5 wherein the arbitrage profit is plotted as a percentage of spot ask price of billet. Wherever the graph is positive, arbitrage was possible at that instant. The height of the graph indicates the magnitude of arbitrage profit that can possibly be made. The graph indicates that cash and carry arbitrage opportunities are frequent, but we need to keep in mind that we have not accounted for several costs that could deter arbitrage, particularly storage costs. Also notice that arbitrage opportunities are clustered together, thereby indicating that such opportunities persist for long periods. We will now account for storage costs.

### 3.1.4 Cash and Carry Arbitrage including storage costs

The equation related to cash and carry arbitrage is: . As long as this equation holds arbitrage will not take place. When , steel billet futures seem overpriced relative to spot steel billet and thus arbitrage takes place. Out of 948 daily observations, there were 20 days when cash and carry arbitrage could take place. The results are summarized in Figure 6 wherein the arbitrage profit is plotted as a percentage of spot ask price of billet. The height of the graph indicates the magnitude of arbitrage profit that can be possibly be made. After including storage costs into our calculations, we observe that the number of days, on which cash and carry arbitrage opportunities was possible, declines significantly. This shows how storage costs can prevent arbitrage from taking place. Nonetheless, the clustering of cash and carry arbitrage opportunities, despite storage costs, suggests that arbitrage opportunities persist. This indicates that the futures and cash spot billet markets are not in synchronization always since arbitrage implies difference in price determination in the two markets.

### 3.1.5 Short-selling arbitrage without convenience yield

The equation related to short-selling arbitrage is: . Arbitrage does not take place as long as the equation holds. When , then spot steel billet seems overpriced relative to steel billet futures. Thus, the arbitrageur will short-sell steel billet in the cash market, and buy steel billet futures. Out of 948 daily observations, we noticed that on 136 days, arbitrageurs could perform short-selling arbitrage. The results are summarized in Figure 7, wherein arbitrage profit is indicated by the height of the graph. Opportunities for short-selling arbitrage are significantly more than opportunities for cash and carry arbitrage. Short-selling arbitrage opportunities are also clustered whenever they arise, indicating the prolonged persistence of such opportunities.

### 3.1.6 Short-selling arbitrage including convenience yield

The equation related to short-selling arbitrage including convenience yield is similar to the one mentioned before: $-$ . We subtract convenience yield since it is a benefit that prevents arbitrage from taking place. Before we test the aforesaid equation, we need to understand the concept of convenience yield and how it is calculated. The next sections elaborate on this concept further and state how we calculate convenience yield.

### 3.1.7 Convenience yield - Definition

Convenience yield refers to the benefit that accrues from holding a commodity, instead of short-selling the commodity as part of an arbitrage strategy. Generally, the term convenience yield applies to firms that either manufacture the commodity or possess large stocks of it as merchants or distributors. When these firms believe that the commodity in concern will become scarce in the future, and thus will fetch significantly higher prices, these firms abstain from short-selling the commodity. This is because, by short-selling the commodity, the firms lose possession of the commodity, and thus become unable to benefit from the any steep rise in prices due to expected scarcity of the commodity in future. Since the commodity is expected to become scarce in the future, the firms may not be able to get hold of the commodity in the future at affordable rates, and thus resell it at a profit. Thus, manufacturers and distributors will keep possession of the commodity if they expect it to become scarce in the future, and yield significant benefits to them due to steep rise in price. In this case, these firms will not provide the commodity to arbitrageurs for the purpose of short-selling arbitrage. Since short-selling arbitrage is dependent on obtaining the commodity for short-selling, the convenience yield acts as a hindrance as it prevents arbitrageurs from obtaining the commodity to short-sell. Thus, in short-selling arbitrage equation, we need to subtract convenience yield, as from the perspective of a firm that could short-sell the commodity that it owns, convenience yield is a benefit that reduces overall cost of holding the commodity.

### 3.1.8 Convenience yield – calculation

Convenience yield, unlike other parameters in the short-selling arbitrage equation, is not directly observable. We need a model of estimating it using the data on futures and spot billet prices. Rajna Gibson and Eduardo Schwartz establish a model of estimating convenience yield for traded commodities. Gibson and Schwartz calculate convenience yield using the following equation:

In the above equation, denotes the periods ahead annualized one month forward convenience yield, denotes the periods ahead annualized one month riskless forward interest rate. denotes the price of the futures contract with expiration after periods. Similarly, denotes the price of the futures contract with expiration after periods. Both the futures prices are calculated using the spot price of the commodity.

In the case of LME steel billet futures, we calculated the 3-months forward convenience yield since the futures are deliverable after 3 months. Since the formula above calculates one-month convenience yield, we had to calculate the 1 month ahead one month forward convenience yield, 2 months ahead one month forward convenience yield and the one month forward convenience yield prevailing now. Using these three figures, we obtained the estimate of the forward convenience yield for the 3 month period from the current day till the expiration of the futures contract. We can now use this 3 month forward convenience yield estimate in our short-selling arbitrage equation. For more details of the calculation of convenience yield, see Appendix C.

### 3.1.9 Results

With the convenience yield calculated using the model provided by Gibson and Schwartz, we tested the short-selling arbitrage equation, inclusive of convenience yield. Out of 948 observations, on 110 days, short-selling arbitrage was possible, even after accounting for convenience yield. With inclusion of convenience yield, the number of short-selling arbitrage opportunities declines, showing that convenience yield can be a deterrent to arbitrage. The results are shown in Figure 8, where the height of the graph indicates the magnitude of arbitrage profit that can be earned by short-selling steel billet and going long on steel billet futures. Once again we observe that short-selling arbitrage opportunities are clustered, indicating that they persist for long periods of time.

#### 3.1.10 Summary of Existence of Arbitrage opportunities

We observe that arbitrage opportunities of both types – cash and carry as well as short-selling exist. Prolonged persistence of both arbitrage opportunities implies that the futures and cash steel billet markets are not efficient, or price determination is not in synchronization in the two markets. As information does not flow simultaneously in both markets, prices in both market follow different paths, and thus arbitrage opportunities arise. When such arbitrage opportunities persist for long periods, the pricing differences also persist. Thus, significant price divergence risk is created and hedgers will be wary of using the contract. The futures contract is rendered ineffective for hedging purposes due to the presence of significant price divergence risk

## 3.2 Profitability of actual arbitrage strategies

Previously, we analyzed whether arbitrage opportunities – both cash and carry and short-selling existed between steel billet futures and cash billet. We discovered that there were several days on which both types of arbitrage could be performed. Using the equations for short-selling and cash and carry arbitrage, we discovered that such arbitrage opportunities persist for long periods. Prolonged persistence could be due to two reasons – either arbitrageurs are not interested in performing the arbitrage transaction due to lack of significant arbitrage profits that could be earned, or arbitrageurs are unable to perform the transaction. In both cases pricing differences cannot be corrected due to the action of arbitrageurs. We will now verify which of these two factors could be responsible for the prolonged persistence of arbitrage opportunities. In other words, we need to ascertain the profitability of different arbitrage strategies. If the strategies are highly profitable then we could rule out the first factor that arbitrageurs do not perform arbitrage due to lack of significant profits. In that case, the reason behind the persistence of arbitrage opportunities will be the inability of arbitrageurs to perform the transaction.

In our analysis of actual arbitrage strategies, we will assume that we are a steel trader with sufficient financing available to purchase a steel futures contract. We shall also assume that any shortfall in finances to implement the arbitrage trade can be obtained easily. Moreover, when the trader purchases or sells a futures contract, he pays or receives the entire amount on the said that. Thus, we ignore the concept of margin accounts for simplicity. Having made these assumptions, let us verify the profitability of three strategies – cash and carry arbitrage, short-selling arbitrage and combination of the two arbitrage strategies. We shall assume convenience yield and storage costs.

### 3.2.1 Cash and carry arbitrage

In order to analyze the profitability of the strategy, assume that a steel trader has sufficient capital to purchase one LME steel billet contract or equivalent tonnage of spot steel billet. We assumed that this capital amount is $1000. Whenever a cash and carry arbitrage is present, the steel trader exploits that and holds the position till expiration. On expiration, he closes the arbitrage position and rakes in profits, if any. We shall calculate the total arbitrage profit that the trader can make, exploiting all arbitrage opportunities in the given price data sample. For simplicity, we can assume that when the trader is currently holding steel billet, and is short on LME steel billet futures, that is, the trader is currently holding the arbitrage position, then the trader cannot exploit any other arbitrage opportunity. In other words, if the trader enters an arbitrage trade on May 21, and is supposed to hold to it for the next three months, then if another arbitrage opportunity arise son May 25, the trader cannot exploit that since he has capital for purchasing one futures contract worth of steel billet. Thus, having made these assumptions, we manually calculated the total arbitrage profit to be: $22. Detailed calculations are shown in Table 4. We did not consider interest rate in our calculation, and thus the arbitrage profit is understated since we can invest arbitrage profits and earn interest on it.

#### 3.2.2 Short-selling arbitrage

We assume that the steel trader can avail of steel billet to short-sell in the spot market. As in the case of cash and carry arbitrage, we assume for simplicity that the trader executes arbitrage opportunities one at a time, since he has capital to purchase only one LME steel billet futures contract or equivalent tonnage of spot steel billet. Once again, we have assumed that the trader has initial capital of $1000. Having made these assumptions, we calculated profit from this strategy to be: $100.5. Detailed calculations are shown in Table 5.

#### 3.2.3 Combination of cash and carry and short-selling arbitrage

Under this strategy the steel trader can execute cash and carry arbitrage as well as short-selling arbitrage simultaneously. For example, assume on December 12, the trader enters a cash and carry arbitrage trade and purchases spot steel billet for the same. If, on December 23, a short-selling arbitrage opportunity presents itself, then the trader can sell the billet that he has and execute the short-selling arbitrage trade as well. On expiration of both trades, he should theoretically earn the sum of the profit of both trades. But we need to investigate whether in practice, the trader earns the sum of the profit of both trades or not. As in previous cases, we assume that the trader can execute combination arbitrage strategies one at a time, due to capital restrictions. We also assumed that the trader starts off with capital of $1000. Thus, he cannot short-sell more than one ton of billet or purchase two tons of billet at the same time. With these assumptions in mind, we calculated profit from this strategy to be: $114.24. Detailed calculations are shown in Table 6.

#### 3.2.4 Interpretation of Profitability analysis

After analyzing the actual profitability of three arbitrage strategies, we observe that in spite of storage costs and convenience yield, the three arbitrage strategies are profitable. Moreover, the amount of arbitrage profits that can be earned is also significant and understated due to non-inclusion of interest rates. Thus the hypothesis that arbitrage opportunities persist for long periods as arbitrageurs are not interested in performing the arbitrage transaction due to low profitability is rejected. The second factor – the inability of arbitrageurs to perform the arbitrage transaction is responsible for the prolonged persistence of arbitrage opportunities.

### 3.3 Summary of Arbitrage Analysis

Our analysis of arbitrage shows that arbitrage opportunities exist for both cash and carry and short-selling arbitrage. At the same time, such arbitrage opportunities persist for long periods. We further investigated the reason behind the persistence of arbitrage opportunities and found that arbitrageurs are unable to perform the transaction and thus correct the pricing differences. Thus, the prolonged persistence of arbitrage opportunities implies that the futures and cash steel billet markets are inefficient. Pricing differences in both markets are prolonged and significant price divergence risk is created. Thus, our arbitrage analysis also suggests that price divergence risk is present for hedgers since markets are inefficient. The arbitrage analysis thus complements our price discovery result that the hedging performance of steel billet futures is severely limited.

# 4. Case Study

Earlier we noticed in section 1.2 that the LME steel billet futures contract has not been perfectly tracking the important physical steel billet markets in East Asia and the Black Sea region. The case study will analyze the structural reasons behind this phenomenon and ascertain whether the phenomenon is likely to persist in the future or not. The case study involved study of several articles.

Our research found that in the recent past, China and Turkey have imposed export duties on the export of steel billet from their ports. These two countries combined produce a large proportion of global steel annually. Due to imposition of huge duties on exports, steel manufacturers in these countries are not using LME warehouses since it has become expensive for them to use the same. Thus, billet stocks from large market makers in China and Turkey are not entering the LME steel billet futures market through delivery of such stocks into LME warehouses. As a result, liquidity in the LME steel billet futures has dropped significantly in these regions. But the trade volume has remained high in the physical markets.

Thus, as large market makers from Turkey and China have been unable to participate in the LME steel billet futures contract, liquidity has declined significantly. As a result, the LME steel billet futures contract has not perfectly tracked the physical billet markets in these regions. The phenomenon is likely to persist in the near term until the duties are removed from the Chinese and Turkish authorities. Until that happens significant price divergence risk will be there for futures contract users in these physical market regions. A steel manufacturer in East Asia will be wary of using the LME steel billet futures contract since he or she knows that the futures price can follow a different path compared to the physical billet markets, and thus he or she may suffer losses due to price divergence. Thus, price divergence risk will make users wary and render futures ineffective for hedging purposes.

## 5. Conclusion

The three methods of analyses – price discovery, arbitrage and case study all suggest the presence of significant price divergence risk for users of the LME steel billet futures contract. As long as price divergence risk is high, the futures contract will be ineffective for hedging purposes. This is because the futures market can follow a different path relative to the spot billet market, and the hedger may end up incurring losses in both the futures hedge and asset positions if prices don't move in his or her favor. Thus, we conclude that owing to significant price divergence risk in using the contract, the LME steel billet futures contract is not an effective hedging tool for steel manufacturers, consumers and merchants.

The implications of the research findings are profound. Metal exchanges worldwide where steel products are traded can lobby for removal of export duties that squeeze liquidity in the futures market. At the same time, research into the causes behind the inability of arbitrageurs to perform arbitrage transactions should be conducted. The research will help in recommending measures to prevent prolonged persistence of arbitrage opportunities.

## Figures and Tables:

**Figure 1:** This figure shows the traded volume of the LME steel billet futures contract from 25/02/2008 to 14/09/2012

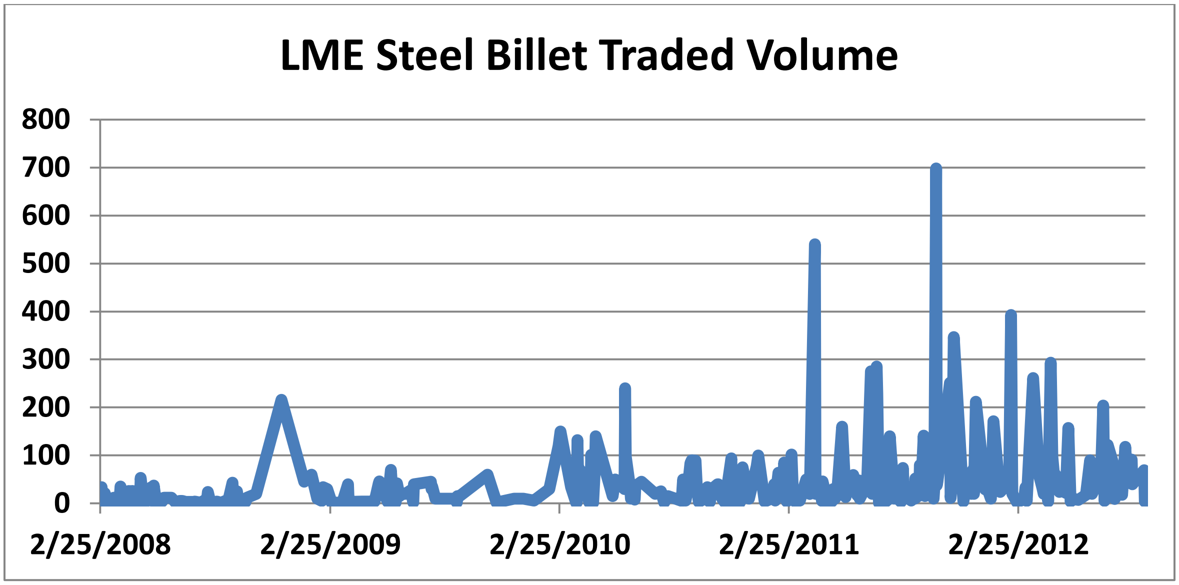


**Figure 2:** This figure shows the prices of the LME steel billet futures against the prices of spot billet in important physical markets in East Asia and the Black Sea region. The two spot billet prices are Black Sea Export FOB Billet and East Asia Import Billet CFR. The terms FOB and CFR mean “Freight on Board” and “Cost and Freight” respectively. We can ignore the implications of these terms and just consider the trends in all three price graphs.

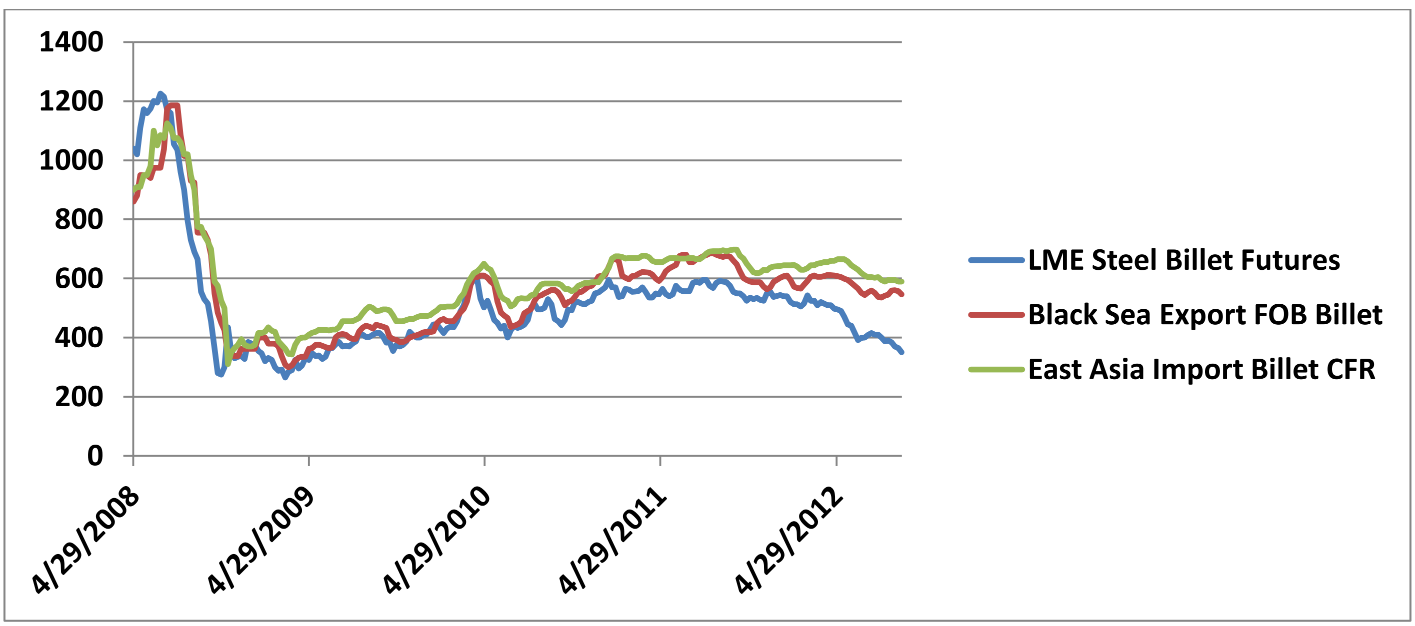

**Figure 3:** This figure shows the elasticity of supply of arbitrage services the steel billet futures contract. The graph is shown for different lag periods from 1 to 60 days.

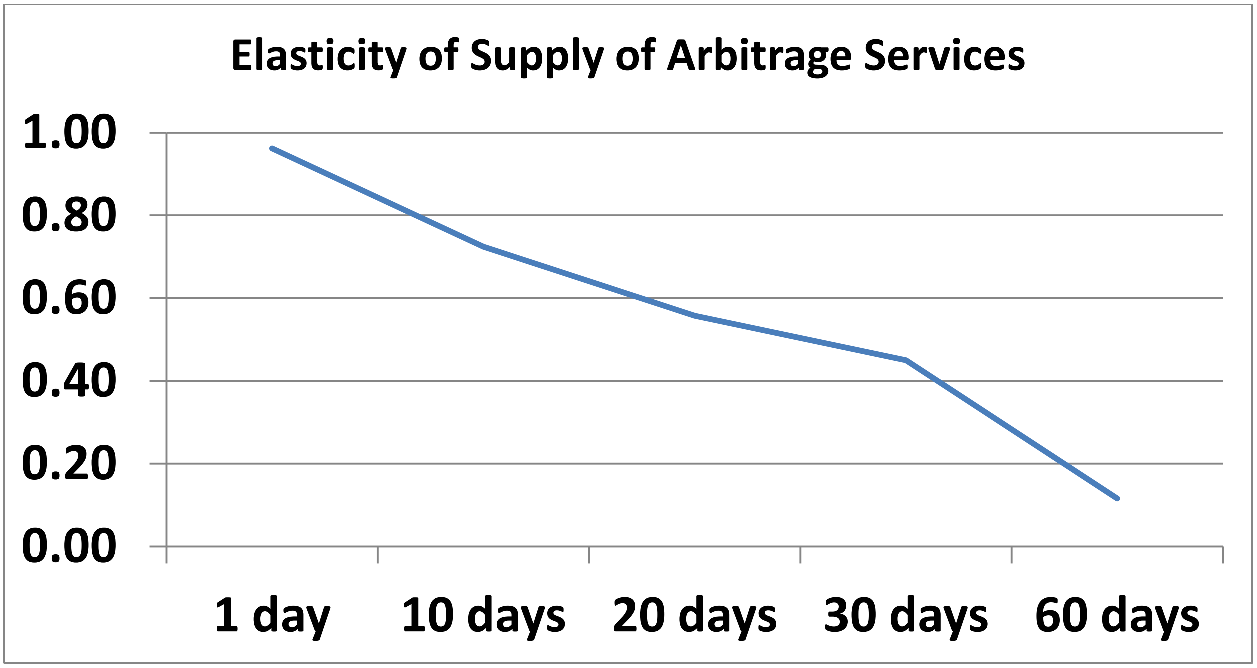


**Figure 4:** This figure shows the elasticity of supply of arbitrage services for four metals and compares it to the elasticity of supply of arbitrage services of steel billet. The four metals compared against billet are copper, aluminum, gold and silver. The elastic is shown for different lag periods from 1 to 60 days.

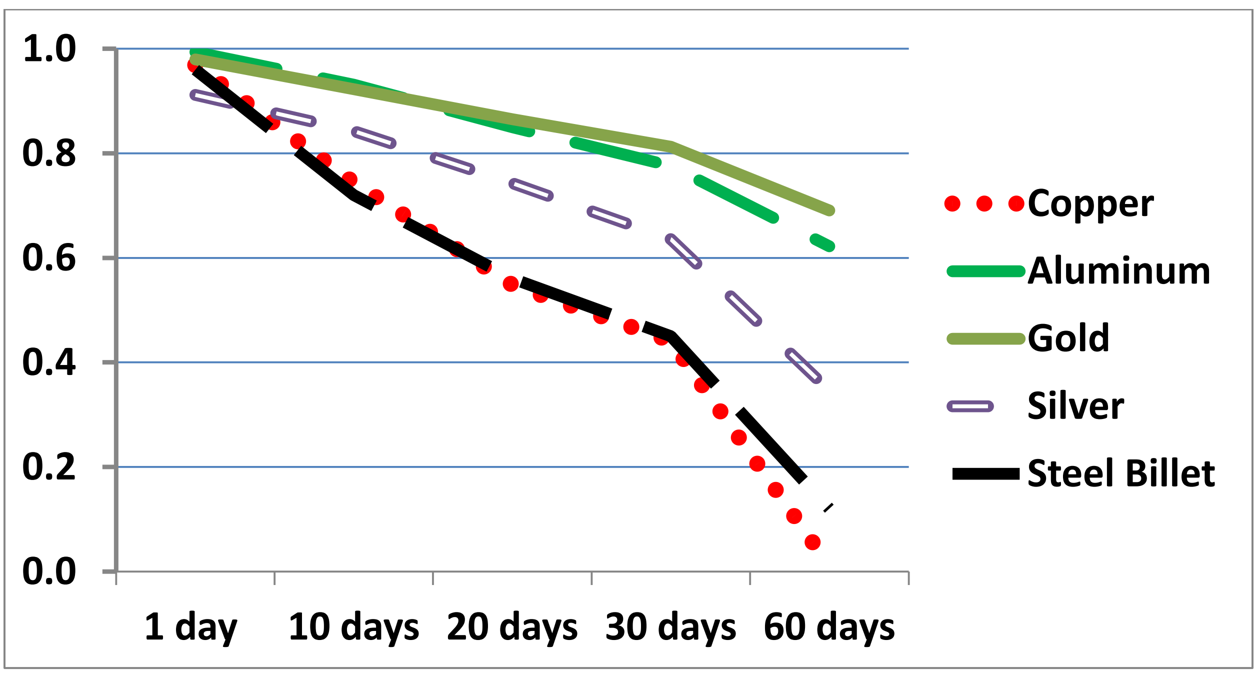

**Figure 5:** This figure shows the arbitrage profits for cash and carry arbitrage, assuming the absence of storage costs.

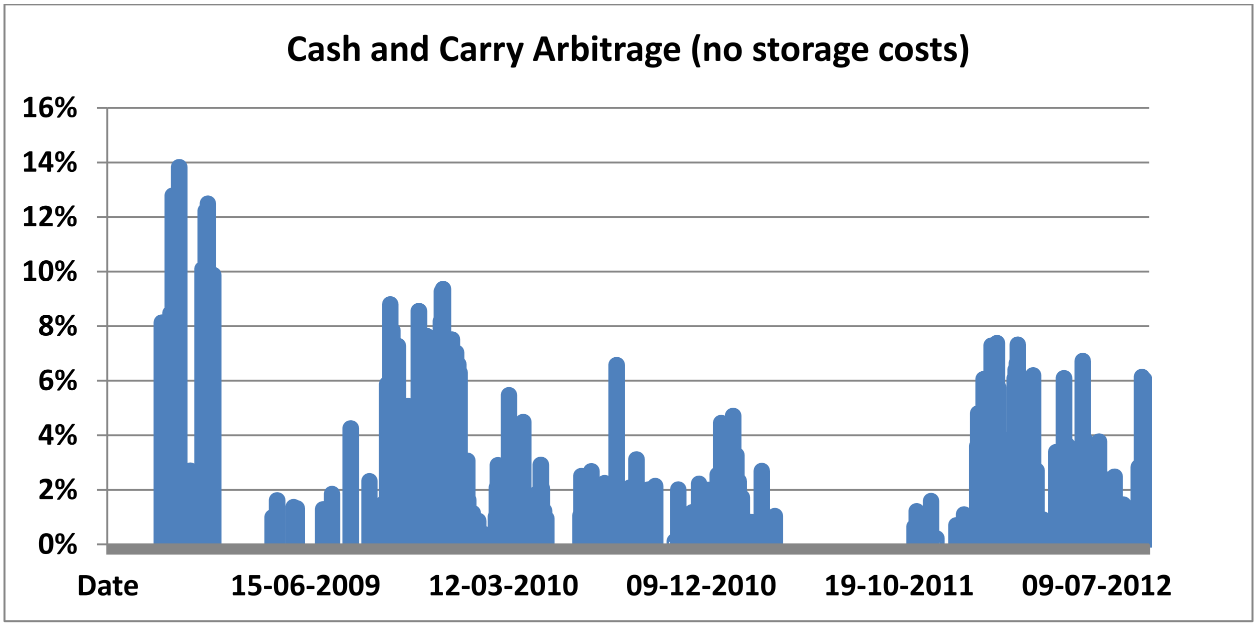


**Figure 6:** This figure shows the arbitrage profits for cash and carry arbitrage, assuming that storage costs are incurred in the holding the spot billet position till the delivery date.

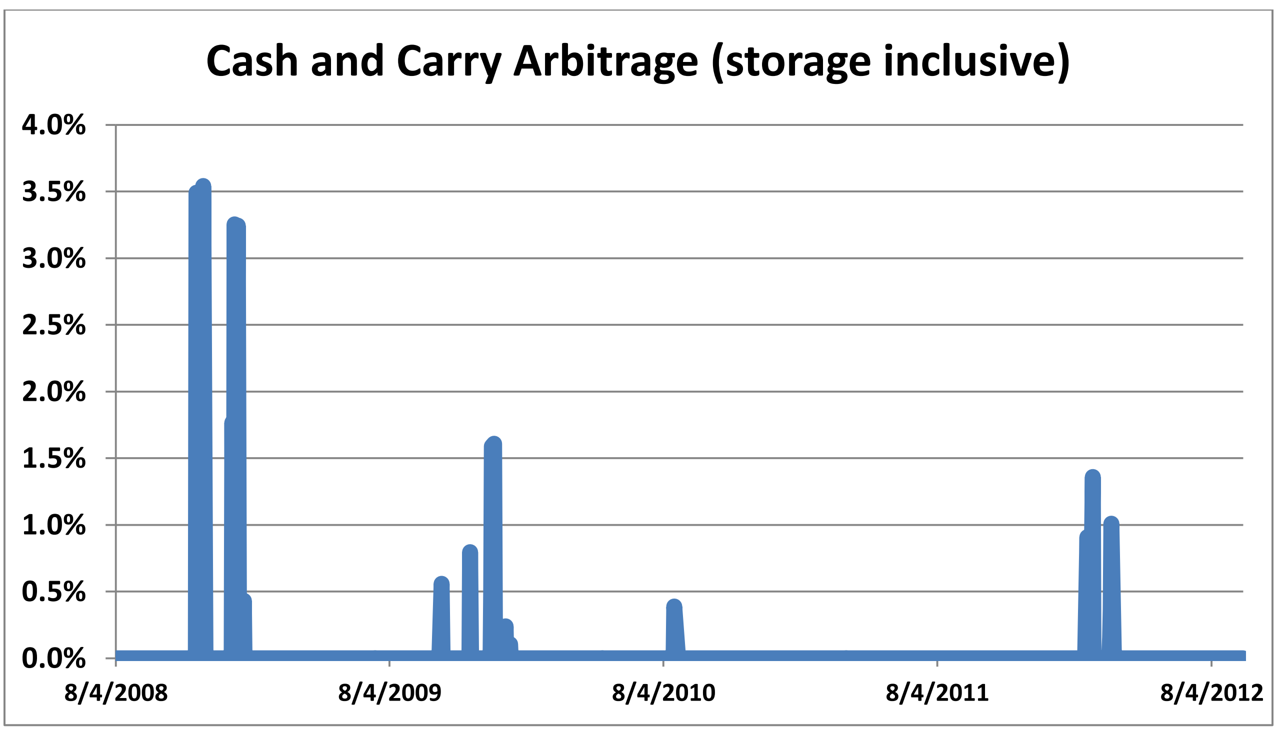

**Figure 7:** This figure shows the arbitrage profits of short-selling arbitrage, assuming the absence of convenience yield.

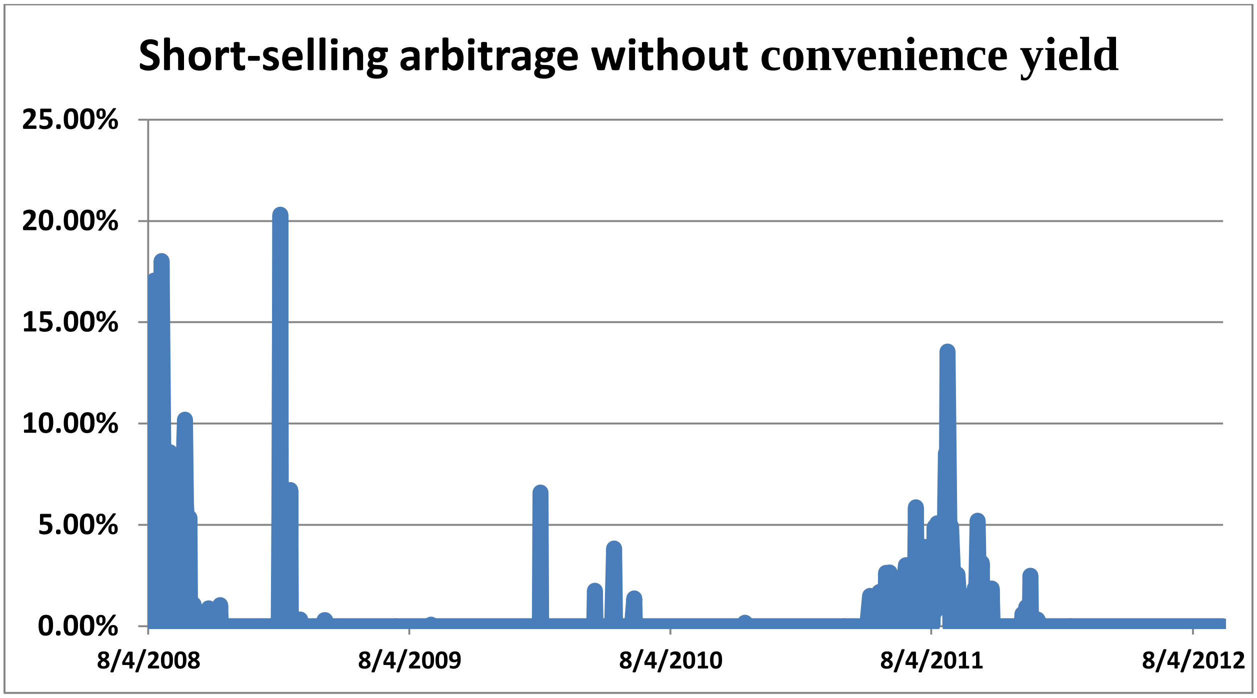


**Figure 8:** This figure shows the arbitrage profits of short-selling arbitrage assuming the presence of convenience yield.

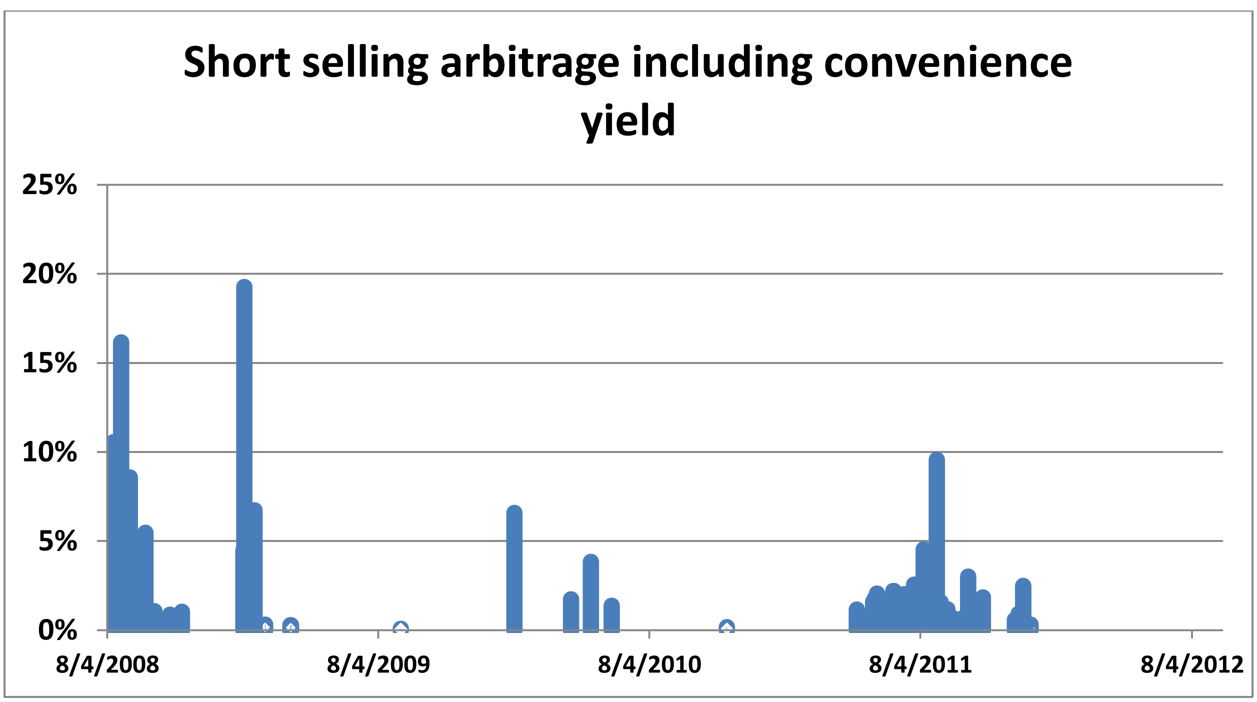

**Table 1:** This table reports the results of the regression on the Market Relationship parameter equations. The estimates of the two parameters that determine the relationship between futures and spot billet prices are shown. Key regression metrics such as the F-statistic, standard error of estimate, t-statistic and p-value are presented. The 95% confidence interval for both parameters is also shown.

| Parameter | Estimate | F-statistic | Standard Error | t statistic | p-value | Lower 95% | Upper 95% |
|---|---|---|---|---|---|---|---|
| | 0.966648 | 38640.49 | 0.005871 | 164.6379 | 0 | 0.955127 | 0.978169 |
| | -0.03226 | 46402.67 | 0.006467 | -4.98805 | 0 | -0.04495 | -0.01957 |

**Table 2:** This table shows the result of regression on the elasticity of supply of arbitrage services equation. The results are showed for different lag periods ranging from 1 to 60 days to display the trend in the value of the elasticity. Key regression metrics such as the standard error in the estimate of elasticity, F-statistic, t-statistic and p-value are also shown to help ascertain whether the regression results are significant.

| Lag period (days) | Value of | Standard Error | F-statistic | t-statistic | p-value |
|---|---|---|---|---|---|
| 1 | 0.96 | 0.00845 | 12963 | 114 | 0 |
| 10 | 0.72 | 0.02 | 1259 | 35 | 0 |
| 20 | 0.56 | 0.02 | 560 | 24 | 0 |
| 30 | 0.45 | 0.025 | 247 | 19 | 0 |
| 60 | 0.12 | 0.027 | 19 | 4.3 | 0 |

**Table 3:** This table shows the value of elasticity of supply of arbitrage services, calculated using Garbade and Silber's model, for different metals such as copper, aluminum, gold, silver, tin and zinc. For the purpose of comparison the value of the elasticity of supply of arbitrage services of steel billet is also displayed. The values are displayed for different lag periods ranging from 1 to 60 days.

| Lag Period (days) | Copper | Aluminum | Gold | Silver | Tin | Zinc | Steel Billet |
|---|---|---|---|---|---|---|---|
| 1 | 0.969 | 0.994 | 0.979 | 0.912 | 0.967 | 0.958 | 0.96 |
| 10 | 0.744 | 0.931 | 0.922 | 0.842 | 0.696 | 0.666 | 0.72 |
| 20 | 0.549 | 0.849 | 0.865 | 0.743 | 0.531 | 0.45 | 0.56 |
| 30 | 0.441 | 0.776 | 0.812 | 0.635 | 0.388 | 0.428 | 0.45 |
| 60 | 0.01 | 0.622 | 0.69 | 0.346 | 0.308 | 0.305 | 0.12 |

**Table 4:** This table shows the calculation of profit of the cash and carry arbitrage strategy. Storage costs are assumed. The beginning and ending net worth reflect the net worth before and after the arbitrage transaction. The spot and futures prices for the respective arbitrage transactions are also shown, along with the date of arbitrage transaction and date of delivery (completion of arbitrage).

| Date | Beginning net worth ($) | Spot price ($) | Futures price ($) | Delivery date | Storage costs ($) | Ending net worth ($) |
|---|---|---|---|---|---|---|
| 19/11/2008 | 1000 | 300 | 340 | 17/02/2009 | 27.9 | 1012.1 |
| 12/10/2009 | 1012.1 | 349 | 380 | 10/01/2010 | 28.8 | 1014.3 |
| 11/01/2010 | 1014.3 | 415.5 | 445 | 11/04/2010 | 28.8 | 1015 |
| 18/08/2010 | 1015 | 465 | 496 | 16/11/2010 | 28.8 | 1017.2 |
| 20/02/2012 | 1017.2 | 465.5 | 500 | 20/05/2012 | 29.7 | 1022 |

**Table 5:** This table shows the calculation of profit of the short-selling arbitrage strategy. Convenience yield is assumed. The beginning and ending net worth reflect the net worth before and after the arbitrage transaction. The spot and futures prices for the respective arbitrage transactions are also shown, along with the date of arbitrage transaction and date of delivery (completion of arbitrage).

| Date | Beginning net worth ($) | Spot Price ($) | Futures Price ($) | Delivery Date ($) | Convenience Yield ($) | Ending Net Worth ($) |
|---|---|---|---|---|---|---|
| 08/08/2008 | 1000 | 1050 | 970 | 06/11/2008 | 84.3 | 995.63 |
| 12/11/2008 | 995.63 | 402 | 400 | 10/02/2009 | 0 | 997.63 |
| 18/02/2009 | 997.63 | 312 | 292 | 19/05/2009 | 0 | 1017.63 |
| 03/02/2010 | 1017.63 | 460 | 430 | 04/05/2010 | 0 | 1047.63 |
| 17/05/2010 | 1047.63 | 457 | 440 | 15/08/2010 | 0 | 1064.64 |
| 10/05/2011 | 1064.63 | 558 | 550 | 08/08/2011 | 1.91 | 1070.72 |
| 08/08/2011 | 1070.72 | 609.5 | 580 | 06/11/2011 | 2.22 | 1098.00 |
| 09/12/2011 | 1098.00 | 554.5 | 552 | 08/03/2012 | 0 | 1100.5 |

**Table 6:** This table shows the calculation of profit of the arbitrage strategy that combines short-selling and cash and carry arbitrage strategies. Convenience yield and storage costs are assumed. Detailed description of every action performed as part of the strategy is provided along with the transaction amount for the given action.The beginning and ending cash reflect the cash before and after the action.

| Date | Beginning cash ($) | Action | Transaction Amount ($) | Ending Cash ($) |
|---|---|---|---|---|
| 08/08/2008 | 1000 | Short sell billet borrowed from distributor | 1050 | 2050 |
| 06/11/2008 | 2050 | Buy billet by taking delivery against futures | (970) | 1080 |
| 06/11/2008 | 1080 | Pay convenience yield and deliver billet to distributor | (84.37) | 995.63 |
| 12/11/2008 | 995.63 | Short sell billet | 402.00 | 1397.63 |
| 19/11/2008 | 1397.63 | Buy billet for cash and carry arbitrage | (300) | 1097.63 |

| | | | | |
|---|---|---|---|---|
| 03/02/2009 | 1097.63 | Short sell billet that you bought, and pay storage costs | 325.13 | 1422.76 |
| 10/02/2009 | 1422.76 | Take delivery against long futures | (400) | 1022.76 |
| 10/02/2009 | 1022.76 | Pay convenience yield and deliver billet to distributor | 0 | 1022.76 |
| 17/02/2009 | 1022.76 | Buy billet for delivery against short futures | (309) | 713.76 |
| 17/02/2009 | 713.76 | Deliver billet against short futures position | 340 | 1053.76 |
| 17/02/2009 | 1053.76 | Close out existing futures position | (46) | 1007.76 |
| 18/02/2009 | 1007.76 | Short sell billet borrowed from distributor | 312 | 1319.76 |
| 19/05/2009 | 1319.76 | Pay convenience yield and deliver billet to distributor | (292) | 1027.76 |
| 19/05/2009 | 1027.76 | Buy billet by taking delivery against futures | 0 | 1027.76 |
| 12/10/2009 | 1027.76 | Buy billet for cash and carry arbitrage | (345) | 682.76 |
| 10/01/2010 | 682.76 | Pay storage costs | (28.8) | 653.96 |
| 10/01/2010 | 653.96 | Deliver billet against short futures position | 380 | 1033.96 |
| 03/02/2010 | 1033.96 | Short sell billet borrowed from distributor | 460 | 1493.96 |
| 04/05/2010 | 1493.96 | Buy billet by taking delivery against futures | (430) | 1063.96 |
| 04/05/2010 | 1063.96 | Pay convenience yield and deliver billet to distributor | 0 | 1063.96 |
| 17/05/2010 | 1063.96 | Short sell billet borrowed from distributor | 457 | 1520.96 |
| 15/08/2010 | 1520.96 | Buy billet by taking delivery against futures | (440) | 1080.96 |
| 15/08/2010 | 1080.96 | Pay convenience yield and deliver billet to distributor | 0 | 1080.96 |

| | | | | |
|---|---|---|---|---|
| 18/08/2010 | 1080.96 | Buy billet for cash and carry arbitrage | (465) | 615.96 |
| 16/11/2010 | 615.96 | Pay storage costs | (28.8) | 587.16 |
| 16/11/2010 | 587.16 | Deliver billet against short futures position | 496 | 1083.16 |
| 10/05/2011 | 1083.16 | Short sell billet borrowed from distributor | 558 | 1641.16 |
| 08/08/2011 | 1641.16 | Buy billet by taking delivery against futures | (550) | 1091.16 |
| 08/08/2011 | 1091.16 | Pay convenience yield and deliver billet to distributor | (1.91) | 1089.25 |
| 10/08/2011 | 1089.25 | Short sell billet borrowed from distributor | 590 | 1679.25 |
| 08/11/2011 | 1679.25 | Buy billet by taking delivery against futures | (570) | 1109.25 |
| 08/11/2011 | 1109.25 | Pay convenience yield and deliver billet to distributor | (2.32) | 1106.94 |
| 09/12/2011 | 1106.94 | Short sell billet borrowed from distributor | 554.5 | 1661.44 |
| 20/02/2012 | 1661.44 | Buy billet for cash and carry arbitrage | (465.5) | 1195.94 |
| 08/03/2012 | 1195.94 | Buy billet by taking delivery against futures | (552) | 643.94 |
| 20/05/2012 | 643.94 | Pay storage costs | (29.7) | 614.24 |
| 20/05/2012 | 614.24 | Deliver billet against short futures position | 500 | 1114.24 |

## Appendix A: Contract Specifications of LME Steel Billet Futures

| | |
|---|---|
| Contract code | FM |
| Underlying metal | Steel billet conforming to nine LME grades of multiple tolerances |
| Prompt dates | • Daily: out to 3 months<br>• Weekly: 3 out to 6 months<br>• Monthly: 7 out to 15 months |
| Price quotation | US dollars per ton |
| Clearable currency | US dollars |
| Trading venues | • Ring: Open-outcry or ring trading is the central platform where LME official prices are established<br>• LMEselect: LMEselect is the official Exchange-operated electronic trading platform<br>• Inter-office telephone: The Exchange also supports an inter-dealer telephone market between LME members which operates 24 hours a day |
| Last trading day | Up until the close of the first Ring the day before the prompt date |
| Settlement type | Physical |
| Delivery locations | Europe – Bilbao, Antwerp, Rotterdam, Ravenna, Tekirdag, Kocaeli; US – New Orleans, Detroit, Chicago; Asia – Dubai, Incheon, Johor |

## Appendix B: Calculation of storage costs

The daily storage cost for the year beginning April 1st, 2012 and ending March 31st, 2013 was 35 US cents per metric ton of steel billet, across all delivery locations mentioned in Appendix A. For the year 2011-12 the storage cost was 33 US cents. We obtained this value of the storage cost from Henry Bath, a company that owns several LME registered warehouses. An important fact about the storage cost figure is that it is constant for an entire year, since Henry Bath fixes it for a year. We assumed that storage costs for other warehouses that are not registered with LME are similar to this value provided by Henry Bath.

For years before 2011-2012, we used inflation numbers from Eurozone to extrapolate the storage costs of 2011-12 to the past. Since the steel industry is highly cyclical and strongly linked to the economy of a region, it can safely be assumed that trends prevailing in the overall economy of a region will also prevail in the steel industry. Thus, we can assume that inflation trends visible in the overall economy will also be visible in the steel industry. Thus, we can deduce storage costs for previous years and future months using inflation values from Eurozone.

However, please note that we could have used inflation numbers from other regions in the world, where LME has registered warehouses for delivery of steel billet. We chose to use Eurozone inflation values as it is clear from Appendix A that most of the LME warehouses are in Europe. Also, we mentioned earlier that the Black Sea region that lies in Europe is the largest hub for steel trading. This is because the Black Sea region is geographically situated midway between steel producers in Europe and Asia, and consumers in the Middle East, Africa and other parts of the world. Thus for deduction of storage costs of previous years and future months, we can safely use inflation values from the Eurozone.

The deduction of storage costs for years prior to 2011-12 was done in the following way: The storage cost for year 2011-12 is 33 cents. Eurozone inflation in year 2011-12 was 3.125%.

Then the storage cost for the beginning of 2011-12 or ending of 2010-11 is: .

Thus for the year 2010-11 the storage cost is 32 (since storage cost is fixed for an entire year). Using this methodology repeatedly we derived storage costs for previous years with 33 cents as the cost for year 2011-12. The storage costs were 32, 32 and 31 US cents for years 2010-11, 2009-10 and 2008-09 respectively. The storage costs for 2011-12 and 2012-13 were 33 and 35 US cents respectively, as mentioned earlier.

## Appendix C: Calculation of convenience yield

Convenience yield is not directly observable in the steel billet futures market and thus we need to empirically estimate it. One such empirical estimation model is provided by Gibson and Schwartz. In their paper Gibson and Schwartz use this model to estimate instantaneous convenience yield for crude oil. But the model is generic and can be used for steel billet also. The equation of the Gibson and Schwartz model is:

denotes the periods ahead annualized one month forward convenience yield.

denotes the periods ahead annualized one month riskless forward interest rate.

denotes the price of the futures contract with expiration after periods. Similarly,

denotes the price of the futures contract with expiration after periods. Both the futures prices are calculated using the spot price of the commodity.

In the short-selling arbitrage equation inclusive of convenience yield, we need a measure of convenience yield for the 3 month period, since the equation yields futures price for delivery period of 3 months. Thus we need to estimate the value of the 3 month forward convenience yield prevailing currently. In order to calculate the 3 month forward convenience yield, we need to estimate , , and .

The equation for is:

Here is the spot 1 month forward riskless interest rate. We used the 1 month LIBOR rate for this parameter. is simply the spot or cash steel billet price. is the price of a billet futures contract deliverable in a month. Now, LME does not have 1 month billet futures contract. Hence, we need to construct the value of this parameter from scratch. Since we observed that number of arbitrage opportunities for cash and carry arbitrage were very few, when we included storage costs, we can use the cash and carry arbitrage equation for calculation of . Thus, we calculated as – where . In this manner, we proceeded to calculate for every day. We take – instead of since here storage costs are incurred for one month only.

For we use the following equation:

Here is the one month ahead 1 month forward riskless interest rate. We can reverse engineer this value using 1 and 2 month LIBOR rates. The requisite equation would be:

— — — . We divide the interest rates by 12 since the interest rates are annualized. was already calculated before. We can use cash and carry arbitrage including storage costs equation to calculate in the following way: – . Note we incur only 2 months storage costs. Also here .

For we use the following equation:

Here is the 2 months ahead 1 month forward riskless interest rate. We can reverse engineer this using 2 and 3 month LIBOR rates. The requisite equation would be:

. was calculated previously. is directly observable as it is the price of the 3 month steel billet futures.

Thus, with our daily values of , , and we can calculate the daily 3 month forward convenience yield . We do this by using the formula:

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