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“Convenience Yield and Inventory Accessibility: Impact of Regional Market Conditions”

Abstract

The theory of storage predicts that convenience yield and inventory level of the same commodity are in an inverse relationship. Conceptually, inventories which are readily accessible by market participants at a given location drive the perceived benefits of owning the physical commodity. The price hike observed in the global base metal markets especially during the pre- and post-global financial crisis period is largely attributed to an exponential consumption growth in Asian countries. Geographical location, according to our study, affects the explanatory power of inventories for changes in convenience yield perceived by market participants at a certain location. In particular, we use data for three different regions, namely, Asia, Americas and Europe, for six major base metals. We test whether one certain region explains the changes of convenience yield better than other regions. Our results indicate that the Asian region is more informative than other regions and thereby accessible inventories are likely to have a stronger impact on the perceived convenience yield.

Keywords: Base metals, convenience yields, futures markets, option pricing, theory of storage, regional supply/demand.

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1. Introduction

Base metals have been playing an important role in global industrial activities. The global base metal demand has experienced a rapid growth thanks to the economic expansion in Asia, especially China whose demand is assumed to have driven the price hike of various commodities during the pre- and post-global financial crisis period (Farooki, 2012). Understanding how the Asian market condition affects the overall global base metal market is becoming increasingly important to market participants. In this paper, we examine the effect of regional market conditions on the convenience yields of six base metals (or industrial use metals), namely, aluminium, copper, lead, nickel, tin and zinc. Specifically, we analyse whether the Asian market has a stronger influence on the behaviour of the global base metal prices than other regions do.

A distinctive feature of relatively durable and consumable commodities, in comparison with other investment products like bonds and stocks, is that physical asset owners obtain benefits from possessing such commodities for a given period (Omura and West, in-press). Those benefits include the possible profit that can be earned from temporary shortages of the commodity as well as the ability to maintain production processes or to meet other obligations while mitigating the risk arising from a supply distraction. Kaldor (1939) labels these benefits as a ‘convenience yield’, which aims to capture the implicit benefits accrued to owning a commodity. Obtaining a clearer understanding of what drives convenience yields is particularly important in practice. This is because the convenience yield represents the relative value of immediate possession of an asset against a futures/forward contract, and therefore changes in such a value directly affect the inventory and investment managing strategy of market participants. Intuitively, convenience yield is represented as the relative value awarded

to the spot price against the futures or forward price of the same commodity and its notion predicts that a positive shock has a larger impact on the spot price than the expected spot price (futures or forward price) especially when the inventory level is low. This is because the impact of a shock on the expected price is partially offset by the response of producers and consumers. As a consequence, higher convenience yields and lower inventory levels are associated with lower expected spot prices. For this reason, the theory of storage states that convenience yield is a negative function of the inventory level (Brennan, 1958).

The inventory level is a crucial component in the study of the theory of storage. However, in many cases inventory information is simply not publically available. To overcome this issue, a number of past studies including Ng and Pirrong (1994) and Stronzik et al. (2009) employ a method called ‘indirect approach’ introduced by Fama and French (1987, 1988). This method uses the sign of interest-adjusted spreads¹ (futures price minus spot price after adjusting for the time value of money) as a proxy of the inventory level. A negative (positive) spread indicates low (high) inventory. Fama and French (1988) use this indirect approach due to the unavailability of accurate aggregate inventory data for base metals. They ascribe this to the lack of a precise definition of ‘aggregate inventory’ and the questionable accuracy of publically available data. For instance, stock data provided by exchanges does not include government owned inventories. Hence, the exchange inventories may not be accurate proxies for aggregate inventory. However, conceptually, following the notion of Gorton et al. (2013), only those inventories accessible by market participants within a given time period should have an impact on the perceived relative value of a spot contract as

¹ Also referred to as a ‘basis’ by Fama and French (1988).

opposed to the corresponding futures or forward contracts. If supply/demand conditions in Asia are driving the base metal market as past studies such as Farooki (2012) observe, the convenience yield dynamics is expected to be better explained by the data from the Asian region than by other regions such as the Americas (including both North and South Americas) and Europe.

Our study aims to examine whether the actual ‘accessibility’ of inventories determines supply shortage risk as well as other benefits that owners of physical assets enjoy. Hence, we further extend the notion of accessible inventory by breaking the exchange stored inventories down to three regions. In particular, we test whether the relationship between convenience yield and inventory levels of base metals is better explained by the market condition in Asia than in other regions (Americas and Europe).

Our study contributes to the existing literature in several important ways. First, to the best of our knowledge, this is the first study to explore the impact of the regional supply/demand environment on the convenience yield of commodities and thereby examine the effectiveness of the concept of ‘accessible inventory’. Second, we examine whether the price of internationally traded commodities is driven by the market conditions in Asia. Third, we further examine the validity of the method which treats convenience yield as a payoff from an option contract. We apply the options-based approach of Milonas and Thomadakis (1997) and West (2012) to estimate convenience yield of base metals. This follows the valuation of option contract payoffs (Heinkel et al., 1990) and unlike the conventional cost-of-carry approach, in theory, convenience yields are bounded by zero².

We study the price behaviour and convenience yields of six major base metals:

² Negative convenience yields imply the existence of arbitrage opportunities.

aluminium, copper, lead, nickel, tin and zinc for the period from January 2000 to May 2014. We find that the market condition in Asia explains the relationship between monthly changes on average convenience yields and inventories of base metals better than other regions. Therefore, it appears that Asia plays a predominant role in determining the price of base metals. Furthermore, market participants take accessibility of the inventory into account when they measure the relative benefits of owning physical assets. Our study also demonstrates that the options-based approach is suitable for estimating regional convenience yields for internationally traded commodities.

The remainder of the paper is structured as follows. Section 2 provides a review of related past studies and the motivation of our study. Section 3 introduces our research question as well as the corresponding hypotheses in the study. Section 4 and 5 present the methodology and the data. Section 6 reports our results. Section 7 concludes.

2. Background

Keynes (1930) argues that speculators would take on a risk by obtaining a forward contract if they can realise a profit and hedgers such as producers are intending to mitigate a price risk by selling the forward contract. Because of this, forward contracts are sold at a value lower than the expected spot price and the gap is explained as a risk premium. While this theory is useful, it fails to provide an explanation as to why the relationship between prices varies over time (Geman and Smith, 2013). Furthermore, researchers such as Watkins and McAleer (2006) reject the validity of this theory on various base metals by comparing how well the cost-of-carry model and the risk premium model explain the long-run relationship between the prices with different maturities.

Kaldor (1939) introduces the notion of convenience yield to explain the spread between spot and futures prices. He claims that possessing physical assets allows the holder to make use of them whenever he/she wishes to. From this reason, a 'benefit' of convenience is awarded to spot prices. Moreover, a physical possession of the asset can be a benefit as it mitigates the risk arising from possible stock-out. A convenience yield represents all these benefits enjoyed by owning the actual asset. One important requirement eliminating arbitrage opportunities is that the convenience yield cannot become negative (Liu and Tang, 2010). A negative value implies that the futures contract is priced higher than the relevant spot contract after considering a necessary cost of storing the commodity. Hence, market participants can obtain a riskless profit by buying an asset in the spot market and selling it in the futures market. Furthermore, this requirement also implies that convenience yields (net of storage costs) cannot be less than the inverse value of the cost of storage (Omura and West, in-press). This asymmetrical profile of convenience yield is particularly important in practice in order to eliminate arbitrage opportunities.

The theory of storage seeks to explain the behaviour of convenience yields by observing the level of inventory of the relevant commodity. The theory states that the inventory absorbs demand and supply shocks on spot prices but because inventory is bounded by zero, a decrease in the inventory level amplifies the risk of stock-out and the volatility of future spot prices (Deaton and Laroque, 1992; Gorton et al., 2013). Based on a fundamental notion, the theory consists of a number of interrelated components that are of interest to this study. First, it is assumed that convenience yields should be negatively correlated with inventories. This relationship is expected to hold as a permanent positive demand shock would push spot prices up but the reaction of

suppliers to increased production would mitigate the impact on futures prices (Fama and French, 1988). Second, it is assumed that the marginal convenience yield on inventory declines at a decreasing rate (Gorton et al., 2013). Third, Routledge et al. (2000) argue that the correlation between spot prices and convenience yields is not constant due to its dependence on inventory and conduct empirical tests that support this hypothesis. They suggest that the correlation between the two variables is higher during backwardation (when the price of a shorter maturity forward contract is higher than that of a distant contract) than contango periods (when the price of a distant forward contract is higher).

An initial concept of the theory of storage is presented by Working (1948, 1949) using wheat data from the US. Brennan (1958) extends the study and introduces the theory of storage. He conducts an empirical study on a wide range of agricultural commodities among which eggs, cheese, butter, wheat and oats. The notion of convenience yield and the theory of storage are also explored in other studies in relation to, for example, grains (Geman and Nguyen, 2005; Gray and Peck, 1981; Paul, 1970), oil (Casassus and Collin-Dufresne, 2005; Casassus et al., 2013; Cho and McDougall, 1990; Geman and Ohana, 2009; Gibson and Schwartz, 1990; Lin and Duan, 2007; Liu and Tang, 2010), natural gas (Geman and Ohana, 2009; Hochradl and Rammerstorfer, 2012; Stronzik et al., 2009), metals (Gao and Wang, 2005; Fama and French, 1988; Geman and Smith, 2013; Heaney, 1998; Liu and Tang, 2010; Stepanek et al., 2013), and bulk commodities like coal (West, 2012). Furthermore, whereas the majority of researchers study the relationship between the convenience yield and the level of scarcity of the same commodity, Casassus et al. (2013) introduce a notion of relative scarcity, led by a complimentary, substitution and production relationship between commodities, to the theory.

Among the first researchers studying base metals based on the theory of storage, Fama and French (1988) show that interest-adjusted spreads estimated from the price difference between two contracts with different maturities (net of interest cost) are more volatile when inventory levels are low. Brunetti and Gilbert (1995) use inventory data of base metals to illustrate that the volatility of spot prices is largely determined by supply/demand fundamentals, and the aggregate inventory level and spot prices are negatively correlated. Ng and Pirrong (1994) use London Metal Exchange (LME) warehouse rental data as a proxy of storage costs and find that the volatility of spot and forward prices directly correlates with the inventory level, which is in line with previous research. Geman and Smith (2013) empirically test the validity of the theory on metals using the interest- and storage-adjusted spread. Their findings indicate the presence of a non-linear relationship between the spread and inventory. Stepanek et al. (2013), applying a cost-of-carry approach, estimate 3, 15 and 27 months futures' convenience yields for five major base metals (aluminium, copper, lead, nickel and zinc) using the relevant longevity futures prices obtained from the LME. They demonstrate that convenience yields can be a good indicator for future supply risk (proxied by spot prices and inventories) of base metals.

Inventory data selection

Inventory is one of the crucial components of the theory of storage; however there are a number of issues associated with compiling the relevant dataset. Researchers including Fama and French (1988) and Cho and McDougall (1990) claim that an 'aggregate inventory' or a 'total stock' should be matched against convenience yield but the accuracy of the available data to represent the stock level of a whole industry is

questioned, especially for internationally traded, consumed and produced commodities. By contrast, Gray and Peck (1981) and Gorton et al. (2013) focus on ‘accessible’ or ‘available’ inventories. This is because a commodity traded on an exchange is delivered in a certain location. Therefore relevant inventories in the study of the theory of storage are those available for immediate and future delivery in the drop-off location.

Gray and Peck (1981) show that the wheat price spread in the Chicago market is more closely related to the behaviour of stocks in Chicago and Toledo than to the US national inventory. By comparing the explanatory power of the US and the aggregate OECD stock information, Geman and Ohana (2009) also demonstrate that the spread of the US crude oil price is influenced more by the immediately available inventory. Furthermore, studying base metals, Geman and Smith (2013) show that whereas adding warehouse stock data from the Commodity Exchange (COMEX) in the US onto the aggregate LME warehouse stocks barely changes the results of their study, adding the stocks from the Shanghai Futures Exchange (SHFE) in China onto the LME improves the results.

Overall, the above studies indicate that market participants are taking into account those inventories available to them when considering the convenience yield of internationally traded commodities, and thereby supply/demand balance in a certain location or region, where a rapid consumption growth is observed, may have a stronger impact than other regions. In other words, since the price of internationally traded commodities is determined by a player who can be located anywhere in the world, market participants in a given location may be depending mostly on their own supply/demand balance and thereby each area may be somewhat isolated from others. This notion makes intuitive sense because convenience yields can be explained as a

value awarded to avoid a supply shortage risk during a given time period³ and therefore stock is required to be located somewhere deliverable within this time frame, at the longest, to be accessible by market players. Conversely, any inventory stored in a warehouse located beyond a reasonable distance from market participants is expected to have a limited impact on the perceived relative value of the physical asset. There would be a larger volume of base metals transported internationally during the demand expansion period as inventories are often unevenly distributed around the world; however, because of the shipping time, the amount of base metals available for consumers in each region at a given time period is constrained by the withdrawal capacity of warehouses in that area. Thus, the behaviour of convenience yields may be better explained by the actual availability during the booming period.

To the best of our knowledge, there is no previous scholarly paper focusing on the influence of the regional supply/demand balance on the convenience yield of base metals. However, since base metals play a crucial role in economic activities, obtaining a better understanding on the price behaviour of base metals is important for market participants such as suppliers and speculators as it would help them construct inventory and investment strategies. In addition to their importance to the world economy, using base metals is related to following advantages in examining the impact of regional supply/demand on convenience yield. First and most importantly, regional warehouse stock information is publically available. Unlike a number of other commodities, regional warehouse inventory can be estimated from the LME warehouse stock, the COMEX and the SHFE. Gorton et al. (2013) express a concern for not covering off-exchange inventories; however, in the case of base metals, Geman and Smith (2013)

³ Three months in the case when convenience yield is estimated using spot and three-month futures contracts.

show that for some metals commercial inventory data weakens the relationship between convenience yield and inventory. We focus on analysing stocks held in approved warehouses of the three major exchanges. Second, it is evident that Asia has been driving the world's base metal consumption growth and price hike over the last few decades (Farooki, 2012). Figure 1 shows that for copper, lead and zinc the combined proportion of the Chinese and Japanese (the two biggest economies in Asia) consumption to the world total has steadily increased from less than 30 per cent in 2000 to around 50 per cent in 2013. For copper and zinc, the growth in demand emerging from these two countries during the same period surpassed the worldwide figure. Furthermore, as a number of countries in Asia do not possess sufficient base metal production capacity, a considerable amount of metals is to be imported. For instance, the World Bureau of Statistics (2013) indicates that China has been importing 3 million metric tonnes of refined copper annually since 2009. The importance of the Asian supply/demand for the world base metal market has experienced a surge. Thus, if convenience yields are determined by actual accessible inventories and the perception of Asian participants regarding the contemporary supply/demand condition is more reflected in base metal prices, convenience yields should be better explained by the regional inventory levels.

Figure 1: The proportion of Chinese and Japanese metal consumption to the world total

Convenience yield estimation model

A number of researchers regard convenience yield as a positive and deterministic function of the spot price (Brennan, 1991; Brennan and Schwartz, 1985; Gibson and Schwartz, 1991). However, a spot price is the maximum of its current consumption and asset values (Routledge et al., 2000) and therefore changes in the spot price do not alter the forward price by the same value. This view is supported by a number of studies indicating that the spot prices and convenience yields are not perfectly correlated. Instead, they demonstrate that a convenience yield exhibits the characteristics of a mean-reverting stochastic variable (Cortazar and Schwartz, 2003; Gibson and Schwartz, 1990; Mirantes et al., 2013; Schwartz, 1997, 1998).

There is a range of models used for estimating the convenience yield and rationalising the phenomenon of commodity spot prices exceeding their forward prices. As convenience yields cannot be observed directly, most studies attempt to estimate the value through the cost-of-carry approach. This method aims at estimating convenience yield from the difference between prices of two forward contracts with different maturities after adjusting for the time value of money and costs associated with carrying asset. In recent studies, Geman and Smith (2013) and Stepanek et al. (2013) use this

approach to estimate convenience yield of base metals. However, even though Stepanek et al. (2013) apply appropriate storage costs and the time value of money in their estimation, negative convenience yields are often obtained. This suggests that the cost-of-carry approach is limited by the output of negative convenience yields, although the model is elegant and simple.

Potential negative convenience yields can be avoided by considering convenience yield as a value of contingent claim for payoff from a call option (Heinkel et al., 1990; Milonas and Thomadakis, 1997). Milonas and Thomadakis (1997) rationalise that the payoff for the convenience yield can be represented as $Max(S_t - F_{(t,T)}, 0)$. Here, S_t is the spot price at time t and $F_{(t,T)}$ is the forward price from time t to T , which is equivalent to the payoff of the option $Max(S_T - K, 0)$, where S_T is the spot price at time T and K is the exercise price (Black and Scholes, 1973). As the option payoff, in theory, is bounded by zero when it is appropriately estimated, this approach avoids the issue of obtaining negative convenience yields. Milonas and Thomadakis (1997) demonstrate the validity of the options approach by modelling the behaviour of soybean, corn, wheat and copper prices. Furthermore, Lin and Duan (2007) and West (2012) use the options approach to study crude oil and coal, respectively. Motivated by these studies, we follow this method in our study.

3. Research Question

As convenience yield is the benefit that can be earned only by owning the physical asset, a commodity is required to be readily available to satisfy the market participants' demand. For instance, if a market participant's intention is to avoid supply shortage, the convenience yield estimated using spot and three-month futures contracts

is the value awarded to overcome such a risk during the following three months, and hence stocks should be accessible within three months at the longest. Nevertheless, with intercontinental transporting it takes several months for a commodity to be delivered. When the demand of a commodity is growing rapidly, stocks stored in distanced warehouses would not sufficiently satisfy the needs of participants at a given location.

We thus pose our research question: ‘How would use of regional data alter the relationship between convenience yield and inventory?’ To answer this question, we propose the following hypotheses.

H1. The relationship between convenience yield and inventory can be better explained by using data for the Asian region than other regions.

H2. Actual accessible inventory determines perceived supply shortage risk and other benefits of possessing a physical asset.

The purpose of examining these two issues is to determine whether there is a spatial limitation in the ‘accessible’ and ‘available’ stocks by market participants in a certain region and a supply/demand balance in each area has different degree of influence on the market. We expect that the Asian stocks are more related to the convenience yield of metals than other regions including the Americas and Europe. We also expect that market participants in Asia have a stronger influence on the global base metal market than elsewhere.

4. Methodology

As discussed earlier, the options approach of Milonas and Thomadakis (1997) and West (2012) can avoid obtaining negative convenience yields. We thus apply this approach to estimate convenience yields. In particular, we follow the approach used by

West (2012), who expresses the convenience yield observed at time t as

$$CY_{t,T}^{Option} = \text{Max} (S_{(t)}^* - F_{(t,T)}, 0), \quad (1)$$

where $CY_{t,T}^{Option}$ is the convenience yield from time t to T . $S_{(t)}^* = S_{(t)} + W_{(t,T)}$ where $S_{(t)}$ is the spot price at time t , $W_{(t,T)}$ is the storage cost from time t to T and $F_{(t,T)}$ is the distant forward price. We assume that both the spot price and the forward price are stochastic and follow standard diffusion processes,

$$dS_{(t)} = \mu_S S_{(t)} dt + \sigma_S S_{(t)} dz_S \quad (2)$$

$$dF_{(t,T)} = \mu_F F_{(t,T)} dt + \sigma_F F_{(t,T)} dz_F \quad (3)$$

where the subscripts S and F represent the spot and futures tenor for each contract type, respectively. Furthermore, we make an assumption that the diffusion terms dz_S and dz_F are uncorrelated. The associated boundary condition is also defined as

$$S_{(t)} \text{Max}(F_{(T)} - 1, 0), \quad (4)$$

where $F_{(T)} = S_{(T)}^*/F_{(t,T)}$. Using Ito's lemma allows us to establish following solution

$$CY_{i,t,T}^{Option} = S_{(i,t)}^* N(d_1) - F_{(t,T)} N(d_2), \quad (5)$$

where

$$d_1 = \frac{\ln[F_{(T)}] + \sigma_c^2 \tau / 2}{\sigma_c \sqrt{\tau}}$$

$$d_2 = d_1 - \sigma_c \sqrt{\tau} = \frac{\ln[F_{(T)}] - \sigma_c^2 \tau / 2}{\sigma_c \sqrt{\tau}}$$

and

$$\sigma_c^2 = \sigma_{S^*(t)}^2 + 2\sigma_{S^*(t)}\sigma_{F(t,T)}\rho_{S(t)F(t,T)} + \sigma_{F(t,T)}^2 \quad (6)$$

σ_c is the volatility of the convenience yield, σ_F is the volatility of the spot and futures prices, $\rho_{S(t)F(t,T)}$ is the correlation coefficient between spot and futures contracts, and τ

is the time period until the maturity of the forward contract. We assume that the spot price is the nearest available tenor and the forward price is represented by the three-month futures contract price. The volatility figures applied in the convenience yield estimation are computed by combining the exponentially weighted moving average (EWMA) for the Parkinson (1980) volatility estimator. Let $\sigma_{t+1|t}^2$ be a volatility estimated by EWMA, λ be an exponential weight coefficient,

$$\sigma_{t+1|t}^2 = (1 - \lambda) \sum_{i=0}^{\infty} \lambda^i R_{t-i} \quad 0 < \lambda < 1 \quad (7)$$

where the subscript ' $t + 1|t$ ' illustrating a forecast at time $t+1$ is based on the available information up to and including time t , and

$$R_{t-i} = \frac{(x_{t-i}^{HL})^2}{4 \times \ln 2} \quad \text{and} \quad x_t^{HL} = \ln \frac{P_{H_{t-i}}}{P_{L_{t-i}}} \quad (8)$$

where P_{H_t} is the intraday high price, and P_{L_t} is the intraday low price. We use $\lambda = 0.94$ as commonly done in the literature and the validity of its empirical rule is justified by J.P. Morgan and Reuters (1996). For the purpose of conducting regression analysis, we estimate daily regional convenience yields using the regional storage costs computed from the average LME warehouse rent in the three regions we study and then average them to obtain monthly values.

We conduct the following regression analysis

$$\Delta CY_{i,t,T} = \beta_0 + \beta_1 [\Delta I_{i,t-1}] + \sum_{j=1}^8 \beta_j [\Delta IP_{j,t-1}] + \varepsilon_t \quad (9)$$

where $\Delta CY_{i,t,T} = [CY_{i,t,T}^{option} / CY_{i,t-1,T-1}^{option} - 1]$ represents the monthly change in convenience yield estimated by the options-based approach (where i : 1 = the world total, 2 = Asia, 3 = Americas and 4 = Europe), $\Delta I_{i,t-1} = [I_{i,t-1} / I_{i,t-2} - 1]$ represents

the one-month lagged monthly change in inventory levels in the relevant region, and $\Delta IP_{j,t-1} = [IP_{j,t-1}/IP_{j,t-2} - 1]$ represents the lagged monthly change in the industrial production of country j (where j : 1 = China, 2 = Japan, 3 = the US, 4 = Canada, 5 = France, 6 = Germany, 7 = UK and 8 = Italy). β_0 , β_1 and β_j are regression parameters, and ε_t is an error term. Following Labys et al. (1999), the industrial production is used as a proxy for the macroeconomic variable. Generally, the industrial production represents the aggregate economic activities of a nation and is expected to widely capture changes in the base metals demand. Hence, the equation is designed to measure how percentage changes in monthly regional convenience yield are related to one-month lagged changes of inventory after controlling for macroeconomic activity (i.e. the industrial production). The broad economic activities in the key nations are expected to affect the demand of base metals and therefore the relationship between convenience yield and inventory is assumed to be highlighted in the regression model by isolating such an impact. The purpose of applying monthly change figures is to overcome the non-stationarity commonly inherent in convenience yield, inventory estimates and industrial production series.

Apart from the above regression model, we use the Spearman (1904) rank correlation statistic to measure the influence of regional inventory. We employ this method because, unlike the Pearson correlation, it can capture a non-linear relationship between two variables. This metric is also used by Geman and Smith (2013). We employ the following model to estimate the correlation coefficient,

$$\rho = 1 - \frac{6 \sum D^2}{N(N^2-1)}, \quad (10)$$

where D is the difference between ranks of monthly changes in the convenience yield at

time t and the inventory at time $t-1$, and N is the number of pairs of the data series. We compare the estimates of ρ for each region.

5. Data

We obtain price and inventory data for six base metals: aluminium, copper, lead, nickel, tin and zinc from DataStream and LME regional inventory data from Bloomberg for the period January 2000 - May 2014. The spot prices are proxied by cash prices and the three-month futures prices are used for distant futures contracts. We select the rolling three-month futures contract as it is the most liquid futures contract for each of the six base metals traded on the LME (Geman and Smith, 2013). The LME is chosen because it is the largest non-ferrous metal exchange in the world (London Metal Exchange, 2013). Additionally, the LME enables full price discovery as it does not impose limits on spot and futures price changes and provides simultaneously quoted spot and futures prices, for fixed forward maturities, for each business day of the sample period (Omura and West, in-press).

The regional inventory volume is estimated by combining the LME, the SHFE and the COMEX. Similarly to Stepanek et al. (2013), the warehouse rental prices obtained from the LME are used as proxies for the storage cost of each base metal employed in the analysis. The data is broken down by region (Americas, Asia, and Europe) in our study. We use three-month U.S Treasury bills from DataStream to represent near-term interest rates. Hence, spot and futures metals price data is synchronised with inventory, storage cost and interest rate data on daily basis. The industrial production for the eight countries under consideration (Canada, China,

France, Germany, Italy, Japan, the UK and the US) are also obtained from DataStream and used to control for the overall base metal demand.

6. Results

First, we apply the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) to examine the stationarity of the considered variables. The test statistics are estimated based on Akaike Information Criterion (AIC). Table 1 shows that, regardless of the region, the majority of the estimated monthly average convenience yields and inventory series are non-stationary (based on a non-zero constant with trend assumption). We therefore convert each series into month-to-month percentage change figures. The ADF tests (zero constant with no trend assumption selected by observing the dataset) are also conducted on the new series and confirm the stationarity at the 5 per cent significance level, except for some zinc inventories where a unit-root can be rejected at the 10 per cent significance level. The results are also presented in Table 1.

Table 1: Unit-root tests for the convenience yields and inventories at different regions

	Monthly average				Monthly change			
	All regions	Americas	Asia	Europe	All regions	Americas	Asia	Europe
Convenience yield								
Aluminium	0.93	0.67	0.93	0.93	0.01**	0.00***	0.00***	0.00***
Copper	0.96	0.96	0.96	0.96	0.00***	0.01**	0.01**	0.01**
Nickel	0.55	0.55	0.55	0.55	0.01**	0.00***	0.00***	0.00***
Lead	0.90	0.89	0.90	0.90	0.00***	0.01**	0.01**	0.01**
Tin	0.44	0.44	0.49	0.44	0.00***	0.00***	0.00***	0.00***
Zinc	0.68	0.68	0.68	0.68	0.00***	0.00***	0.00***	0.00***
Inventory								
Aluminium								
LME	0.69	0.86	0.97	0.97	0.00***	0.00***	0.00***	0.00***
+SH	0.74	NA	0.95	NA	0.00***	NA	0.00***	NA
Copper								
LME	0.23	0.59	0.00***	0.05*	0.01**	0.00***	0.04**	0.00***
+SH	0.35	NA	0.09*	NA	0.00***	NA	0.00***	NA
+SH+COM	0.44	0.30	NA	NA	0.00***	0.01**	NA	NA
Nickel								
LME	0.87	0.53	0.99	0.46	0.00***	0.01**	0.00***	0.00***
Tin								
LME	0.21	0.04**	0.12	0.62	0.00***	0.00***	0.00***	0.00***
Zinc								
LME	0.90	0.73	0.69	0.37	0.07*	0.07*	0.02**	0.00***
+SH	0.90	NA	0.88	NA	0.06*	NA	0.05*	NA

Note: The table presents results of unit-root test (ADF test) on the convenience yield and inventory of six base metals. The displayed numbers are p-values. Number of lag is automatically selected based on AIC with a maximum lag of 12. Rejection of the null-hypothesis (H0: the variable contains a unit-root) with each significance level is displayed by ***=1%, **=5% and *=10%. For monthly average figures an assumption of non-zero constant with trend is used and for the series of month-to-month percentage change in monthly average zero constant with no trend is used. '+SH' implies LME plus SHFE warehouse inventory and '+SH+COM' implies sum of the LME, SHFE and COMEX. The figures inserted in the cell for Americas inventories at '+SH+COM' are LME plus COMEX. 'NA' indicates that no relevant data exists, e.g., SHFE data is only relevant for all regions combined and Asia.

Figure 2 displays the relationship among convenience yield, spot price and inventory levels for six base metals. As expected, there is no negative convenience yield observed in the figure, which is in line with the theory of storage. In general, convenience yields are shown to be positively related to spot prices, which is consistent with Brennan (1991), Brennan and Schwartz (1985) and Gibson and Schwartz (1991). However, the association between two variables for some metals like aluminium, copper, nickel and zinc appears to have weakened in the recent period. This is possibly because the perspective of stock-out risk eased as the result of increase in inventory levels and thereby the relative benefit of owning physical metal has declined. This is

consistent with the notion of a convenience yield.

Figure 2: Convenience yield, spot price and inventory

Note: CY = convenience yields for all regions combined, MT = metric tonne, Al = aluminium, Cu = copper, Pb = lead, Ni = nickel, Sn = tin and Zn = zinc. Inventory = LME inventory. The unit is January 2000 = 100.

Table 2 reports the descriptive statistics of monthly changes in convenience yields. It shows that regional convenience yields estimated by applying regional storage costs (proxied by the LME warehouse rents) behave similarly to convenience yields computed by factoring data from all regions. By contrast, regional inventories tend to fluctuate more than aggregate inventories (see Table 3) due to the level of regional inventories being considerably lower than the overall figure, so that the impact of storing or withdrawing the metal is relatively larger. For instance, copper inventory in the Asian region increased to 40 thousand metric tonnes (MT) from a few hundred MT between April-September 2004.

Table 2: Descriptive statistics for monthly changes of regional convenience yields

<u>All regions</u>							<u>Asia</u>					
	Al	Cu	Pb	Ni	Sn	Zn	Al	Cu	Pb	Ni	Sn	Zn
Mean	2.2	2.3	2.1	3.2	3.0	1.9	2.2	2.3	2.2	3.2	3.1	1.9
Median	-1.0	0.1	1.6	-1.6	-2.5	-0.9	-1.0	0.1	1.6	-1.6	-2.4	-0.9
Standard Deviation	22.9	17.8	17.3	25.9	23.1	19.6	22.8	17.8	17.2	25.9	22.2	19.6
Kurtosis	0.8	3.0	-0.2	7.6	3.4	3.7	0.8	3.0	-0.2	7.6	2.4	3.6
Skewness	0.8	1.2	0.4	2.0	1.6	1.4	0.8	1.2	0.4	2.0	1.4	1.3
Minimum	-43.3	-34.9	-34.9	-37.5	-36.5	-47.5	-42.9	-34.9	-34.8	-37.5	-36.5	-47.4
Maximum	87.7	85.8	48.9	156.3	104.4	87.6	87.2	85.7	49.0	156.2	87.2	87.4
<u>Americas</u>							<u>Europe</u>					
	Al	Cu	Pb	Ni	Sn	Zn	Al	Cu	Pb	Ni	Sn	Zn
Mean	2.2	2.3	2.1	3.2	3.0	1.9	2.2	2.3	2.1	3.2	3.0	1.9
Median	-0.9	0.1	1.6	-1.6	-2.6	-0.9	-1.0	0.1	1.6	-1.6	-2.5	-0.9
Standard Deviation	22.9	17.7	17.2	25.9	23.1	19.6	22.9	17.8	17.3	25.9	23.1	19.6
Kurtosis	0.8	3.1	-0.2	7.6	3.4	3.7	0.8	3.0	-0.2	7.6	3.4	3.7
Skewness	0.8	1.2	0.4	2.0	1.6	1.4	0.8	1.2	0.4	2.0	1.6	1.4
Minimum	-43.3	-34.9	-35.0	-37.5	-36.5	-47.5	-43.3	-34.9	-35.0	-37.5	-36.5	-47.5
Maximum	88.1	85.8	48.9	156.4	104.6	87.8	87.8	85.8	48.9	156.3	104.4	87.6

Note: Unit = per cent, Al = aluminium, Cu = copper, Pb = lead, Ni = nickel, Sn = tin and Zn = zinc.

Table 3: Descriptive statistics for monthly changes of regional LME inventories

<u>Copper</u>					<u>Nickel</u>			
	All regions	Americas	Asia	Europe	All regions	Americas	Asia	Europe
Mean	0.2	41.0	20.1	105.6	2.5	14.5	23.6	4.5
Median	-1.9	-1.9	-2.2	-5.0	2.1	0.0	1.2	0.8
Standard Deviation	14.9	378.1	136.2	1,230.7	17.3	93.5	228.1	37.2
Kurtosis	765.9	11,363.0	5,913.8	17,046.5	473.5	3,367.8	16,228.9	6,571.1
Skewness	165.2	1,034.0	722.3	1,302.9	107.2	541.2	1,256.8	661.5
Minimum	-32.4	-95.7	-94.5	-92.6	-53.3	-94.3	-87.4	-81.1
Maximum	91.2	4,438.1	1,293.8	16,117.4	82.3	716.9	2,955.5	386.4
<u>Aluminium</u>					<u>Tin</u>			
	All regions	Americas	Asia	Europe	All regions	Americas	Asia	Europe
Mean	1.3	71.3	9.3	1.3	1.0	51.9	1.9	43.4
Median	0.3	0.0	0.1	0.3	0.0	0.0	0.2	-6.0
Standard Deviation	6.6	601.3	64.4	10.0	14.2	581.7	17.5	264.0
Kurtosis	257.4	12,683.2	9,750.1	852.1	362.0	14,870.4	432.3	3,541.9
Skewness	86.3	1,087.9	922.4	197.7	88.3	1,211.9	93.3	570.3
Minimum	-12.7	-86.3	-67.9	-20.8	-42.3	-86.1	-57.1	-93.1
Maximum	26.8	7,314.3	733.9	54.4	69.0	7,150.0	77.8	2,019.0
<u>Lead</u>					<u>Zinc</u>			
	All regions	Americas	Asia	Europe	All regions	Americas	Asia	Europe
Mean	0.8	11.0	12.4	14.0	0.9	2.4	1.2	1.1
Median	-0.5	-0.1	-0.6	-1.1	0.8	0.5	-0.5	-1.5
Standard Deviation	12.9	95.7	72.3	109.6	7.9	9.2	21.8	23.3
Kurtosis	298.5	7,440.4	3,586.6	8,084.9	261.0	484.8	3,272.6	2,493.4
Skewness	91.2	827.0	509.1	849.7	55.6	151.6	414.5	446.8
Minimum	-30.4	-84.4	-95.3	-93.2	-25.5	-25.7	-58.2	-37.8
Maximum	60.6	957.9	627.5	1,163.0	32.5	40.3	187.7	168.5

Note: Unit = per cent, Al = aluminium, Cu = copper, Pb = lead, Ni = nickel, Sn = tin and Zn = zinc.

Table 4 presents the results of the regression analysis for month-to-month

percentage changes in convenience yields against the corresponding changes in the inventory levels using all regions together (Equation (9)). We use White's robust standard errors to estimate t-values for the metals potentially affected by heteroscedasticity (identified with the Breusch-Pagan test). The results suggest that most control variables have an insignificant impact. As industrial production reflects the broad macroeconomic production activity of the country, it may not well represent the demand of each metal. Overall, consumption appears not to be as informative as inventory in considering convenience yield. Geman and Smith (2013) show that using inventory in days of world consumption (inventory divided by the world annual consumption) instead of ordinary inventory worsens the results.

By contrast, the coefficient estimates for inventory are statistically significant and negative for aluminium and tin, for models using LME only and LME together with SHFE data. In addition, although the coefficient estimates for inventory are insignificant in the model for copper and zinc when regressed against LME, the inclusion of other exchanges onto LME achieves significant results. Furthermore, the results show low values for the coefficient of determination. A number of base metals are amenable to recycling which means they will be remelted into a form of alloy for use directly in a different type of finished product (Eiji Hosoda Inter Seminar, 2007). These alloys are not exchange-traded because they do not comply with contract specifications of futures markets. The presence of these off-exchange markets may have an effect on our coefficient of determination results.

**Table 4: Regression analysis results: Convenience yield versus inventories
(all regions)**

	Al		Cu			Pb		Ni	Sn	Zn	
	LME	+SH	LME _{rob}	+SH _{rob}	+SH _{COM} _{rob}	LME	+SH	LME _{rob}	LME _{rob}	LME _{rob}	+SH _{rob}
R ²	0.11	0.11	0.05	0.06	0.07	0.13	0.13	0.04	0.09	0.09	0.10
Adj R ²	0.05	0.05	-0.01	-0.00	0.01	0.07	0.07	-0.02	0.04	0.04	0.04
β ₀	2.101	1.454	-4.387	-4.483	-3.910	3.709	3.775	-2.717	-3.754	-5.527*	-5.764*
(p-value)	0.70	0.79	0.19	0.18	0.23	0.35	0.34	0.62	0.45	0.09	0.07
Invent (t-1)	-0.817***	-0.753**	-0.120	-0.198*	-0.271**	-0.126	-0.124	-0.184	-0.361**	-0.365	-0.453*
(p-value)	(0.01)	(0.01)	(0.10)	(0.08)	(0.03)	(0.24)	(0.25)	(0.14)	(0.01)	(0.11)	(0.06)
FR (t-1)	1.845	1.851	1.763	1.965	2.037	1.546	1.539	-1.559	3.855**	0.656	0.628
(p-value)	(0.27)	(0.27)	(0.18)	(0.13)	(0.11)	(0.23)	(0.23)	(0.42)	(0.01)	(0.66)	(0.68)
UK (t-1)	-2.823	-3.067	-0.058	-0.144	-0.187	-3.044**	-3.044**	1.849	0.871	-1.514	-1.533
(p-value)	(0.16)	(0.13)	(0.97)	(0.92)	(0.89)	(0.05)	(0.05)	(0.37)	(0.63)	(0.31)	(0.30)
US (t-1)	-4.924	-4.969	-1.754	-1.614	-1.808	-3.544	-3.550	-0.026	-3.290	-2.928	-2.865
(p-value)	(0.10)	(0.10)	(0.37)	(0.42)	(0.36)	(0.12)	(0.11)	(0.99)	(0.30)	(0.14)	(0.15)
JP (t-1)	-1.189	-1.205	-0.297	-0.379	-0.433	-0.433	-0.424	0.459	-0.110	-0.288	-0.263
(p-value)	(0.17)	(0.17)	(0.61)	(0.51)	(0.44)	(0.51)	(0.52)	(0.60)	(0.87)	(0.56)	(0.60)
CN (t-1)	-0.632	-0.605	0.080	0.100	0.132	-0.988**	-0.989**	-0.786	-0.770*	-0.723	-0.688
(p-value)	(0.29)	(0.31)	(0.89)	(0.86)	(0.81)	(0.03)	(0.03)	(0.16)	(0.09)	(0.14)	(0.16)
CA (t-1)	3.926	4.625	3.952	3.954	3.689	-1.146	-1.217	1.024	4.282	7.704**	7.874**
(p-value)	(0.50)	(0.43)	(0.30)	(0.30)	(0.33)	(0.79)	(0.78)	(0.87)	(0.48)	(0.05)	(0.04)
DE (t-1)	-0.547	-0.569	0.952	0.825	0.675	1.649	1.666	1.135	-0.218	1.566	1.572
(p-value)	(0.70)	(0.69)	(0.49)	(0.54)	(0.61)	(0.12)	(0.12)	(0.50)	(0.87)	(0.23)	(0.22)
IT (t-1)	2.271	2.512	-0.244	-0.217	-0.189	2.278*	2.270*	0.657	-0.835	1.064	1.049
(p-value)	(0.16)	(0.12)	(0.84)	(0.86)	(0.88)	(0.06)	(0.06)	(0.74)	(0.55)	(0.34)	(0.34)

Note: The table reports the results of the regression

$$\Delta CY_{i,t,T} = \beta_0 + \beta_1 [\Delta I_{i,t-1}] + \sum_{j=1}^8 \beta_j [\Delta IP_{j,t-1}] + \varepsilon_t,$$

where CY = convenience yield, I = inventory, IP_j = industrial production of country j (where 1 = China = CN, 2 = Japan = JP, 3 = the US = US, 4 = Canada = CA, 5 = France = FR, 6 = Germany = DE, 7 = the UK = UK and 8 = Italy = IT). Monthly data pertains to the period between January 2000 and May 2014. The results are tested for heteroscedasticity by the Breusch-Pagan test and White's robust standard error is used for those models that fail to reject the heteroscedasticity hypothesis (they are indicated as 'rob.' in the table). 'Invent' refers to the inventory. Significance level displayed by ***=1%, **=5% and *=10%. '+SH' implies LME plus SHFE warehouse inventory and '+SH+COM' implies sum of the LME, SHFE and COMEX.

Additionally, we rerun the regression analysis using data for the three major regions separately (Asia, Americas and Europe). The results are reported in Table 5. The control variables again show statistically insignificant results in most cases. For Asia, the same metals as in the case when all regions are considered together (aluminium, copper, tin and zinc) show significant inventory coefficients. In particular, the negative coefficients for aluminium, copper and tin are significant for models with LME (aluminium also shows a significant result with LME plus SHFE). Additionally, another significant result is obtained in the model for zinc when SHFE inventory is added onto

the LME. In contrast, negative but insignificant inventory coefficients are obtained in the model for lead and nickel.

The regression results strongly support our view that the relationship between convenience yields and inventory levels of base metals are better explained by the Asian data than other regions. For the Americas and Europe, we fail to reject the null hypothesis of no relationship between convenience yields and inventory levels in most of the metals. In particular, solely aluminium and tin exhibit negative and statistically significant inventory coefficients in the case of Americas while for Europe, a significant relationship is observed only in the case of copper.

**Table 5: Regression analysis results: Convenience yield versus inventories
(Asia, Americas and Europe)**

Asia										
	Al		Cu		Pb		Ni	Sn	Zn	
	LME	+SH	LME ^{rob}	+SH	LME ^{rob}	+SH ^{rob}	LME	LME ^{rob}	LME ^{rob}	+SH ^{rob}
R ²	0.046	0.043	0.015	0.006	0.030	0.030	0.013	0.038	0.020	0.034
Adj R ²	0.026	0.024	-0.005	-0.014	0.011	0.010	-0.007	0.015	0.001	0.015
β ₀	1.270	1.269	-0.414	-0.419	1.136	1.135	0.158	-0.184	0.373	0.371
(p-value)	0.19	0.19	0.56	0.57	0.17	0.17	0.89	0.85	0.58	0.58
Invent (t-1)	-0.058**	-0.055**	-0.013***	0.009	-0.012	-0.011	-0.006	-0.231**	-0.072	-0.217**
(p-value)	(0.04)	(0.05)	(0.00)	(0.50)	(0.72)	(0.73)	(0.54)	(0.04)	(0.34)	(0.02)
JP (t-1)	-0.585	-0.583	0.198	0.197	-0.181	-0.179	0.573	0.706	0.374	0.311
(p-value)	(0.47)	(0.48)	(0.71)	(0.75)	(0.79)	(0.79)	(0.55)	(0.23)	(0.48)	(0.56)
CN (t-1)	-0.658	-0.660	0.233	0.235	-0.932**	-0.932**	-0.695	-0.485	-0.726	-0.659
(p-value)	(0.27)	(0.27)	(0.66)	(0.60)	(0.06)	(0.06)	(0.32)	(0.47)	(0.14)	(0.17)

Americas							
	Al	Cu		Pb	Ni	Sn	Zn
	LME	LME	+COM	LME	LME	LME ^{rob}	LME ^{rob}
R ²	0.034	0.018	0.017	0.002	0.005	0.011	0.038
Adj R ²	0.016	-0.000	-0.001	-0.015	-0.017	-0.009	0.021
β ₀	-3.107	-5.534	-4.893	0.561	-3.578	-0.724	-7.815**
(p-value)	0.52	0.14	0.20	0.88	0.57	0.91	0.03
Invent (t-1)	-0.005*	0.003	-0.417	0.001	-0.000	-0.004***	-0.189
(p-value)	(0.06)	(0.35)	(0.40)	(0.97)	(1.00)	(0.00)	(0.20)
US (t-1)	-3.348	-0.274	-0.559	-1.304	2.424	-2.708	-1.858
(p-value)	(0.22)	(0.90)	(0.79)	(0.53)	(0.49)	(0.60)	(0.30)
CA (t-1)	6.471	5.819	5.466	0.762	1.189	3.461	9.683**
(p-value)	(0.22)	(0.16)	(0.18)	(0.85)	(0.86)	(0.62)	(0.02)

Europe						
	Aluminium	Copper	Lead	Nickel	Tin	Zinc
	LME	LME ^{rob}	LME	LME	LME ^{rob}	LME ^{rob}
R ²	0.048	0.039	0.067	0.023	0.026	0.055
Adj R ²	0.019	0.010	0.039	-0.006	-0.005	0.027
β ₀	0.34	-2.92*	-1.21	-3.10	-2.26	-2.77*
(p-value)	(0.877)	(0.058)	(0.426)	(0.182)	(0.264)	(0.080)
Invent (t-1)	-0.225	-0.001***	-0.003	-0.036	0.000	-0.054
(p-value)	0.24	0.00	0.78	0.50	0.99	0.22
(FR (t-1))	1.053	1.540	1.041	-1.724	2.979**	0.718
p-value	0.51	0.22	0.39	0.35	0.04	0.60
UK (t-1)	-3.048	-0.228	-2.823**	2.478	0.644	-1.086
(p-value)	(0.11)	(0.87)	(0.05)	(0.26)	(0.74)	(0.48)
DE (t-1)	-0.830	1.029	1.398	1.626	0.126	1.318
(p-value)	(0.54)	(0.40)	(0.16)	(0.28)	(0.92)	(0.27)
IT (t-1)	2.515*	0.599	1.619	0.754	-1.467	1.838*
(p-value)	(0.09)	(0.64)	(0.13)	(0.64)	(0.28)	(0.08)

Note: The table reports the results of the regression

$$\Delta CY_{i,t,T} = \beta_0 + \beta_1 [\Delta I_{i,t-1}] + \sum_{j=1}^8 \beta_j [\Delta IP_{j,t-1}] + \varepsilon_t,$$

where CY = convenience yield, I_i = regional inventory (Asia, Americas and Europe), IP_j = industrial production of country j (where j is 1 = China = CN, 2 = Japan = JP for Asia, 3 = the US = US and 4 = Canada = CA for Americas, and 5 = France = FR, 6 = Germany = DE, 7 = the UK = UK and 8 = Italy = IT for Europe). Monthly data pertains to the period between January 2000 and May 2014. White's robust standard error is used for those models that fail to reject the heteroscedasticity hypothesis (they are indicated as 'rob.' in the table). 'Invent' refers to the inventory. Significance level displayed by ***=1%, **=5% and *=10%. '+SH' implies LME plus SHFE warehouse inventory and '+COM' implies LME plus COMEX.

Next, we compare the Spearman rank correlation between monthly changes of convenience yield and lagged inventory change as a robustness check. Table 6 shows that all statistically significant results have a negative correlation as predicted by the theory of storage. Our results for all regions taken together generate lower correlation coefficients compared with previous studies (i.e. Geman and Smith, 2013). This difference may be arising from the use of the lagged inventory instead of simultaneous inventory or the month-to-month change to overcome a unit-root problem observed in our dataset.

The results indicate the superiority of Asian data against all regions considered together as well as against Americas and Europe. For Asia, the results indicate that there is a significant relationship between convenience yield and lagged inventory for all six metals (with the LME inventories). By contrast, there are only 4 metals (aluminium, lead, tin and zinc) showing such a relationship in the case for all regions combined. Overall, the Asian region appears to have a stronger explanatory power than the aggregate data based on the Spearman rank correlation as all six metals show significant results when the Asian data is used, whereas only four metals show significant results when all regions are combined. Moreover, consistent with the previous regression results, Asia demonstrates its superiority against two other regions. There is a significant relationship observed in the model for aluminium for both Americas and Europe but we fail to reject the null hypothesis (monthly change convenience yield and lagged inventory are independent) for other metals at the 10 per cent significance level. The results indicate that adding of Americas and Europe may weaken the relationship between convenience yields and inventory levels.

Table 6: Spearman rank correlation results: convenience yield vs lagged inventories

	Aluminium						
	All regions	Asia		Americas		Europe	
	LME	+SH		+SH	LME	LME	LME
Correlation	-0.24***	-0.19**	-0.14*	-0.10	-0.15*	-0.20***	
(p-value)	(0.00)	(0.01)	(0.06)	(0.18)	(0.05)	(0.01)	

	Copper							
	All regions	Asia			Americas		Europe	
	LME	+SH	+SH+COM	LME	+SH	LME	+COM	LME
Correlation	-0.10	-0.09	-0.12	-0.13*	0.06	-0.01	-0.09	-0.05
(p-value)	(0.21)	(0.26)	(0.12)	(0.08)	(0.40)	(0.94)	(0.27)	(0.50)

	Lead						Nickel			
	All regions	Asia		Americas		Europe	All regions	Asia	Americas	Europe
	LME	+SH	LME	+SH	LME	LME	LME	LME	LME	LME
Correlation	-0.18**	-0.17**	-0.13*	-0.11	-0.04	-0.10	-0.09	-0.19**	0.09	-0.07
(p-value)	(0.02)	(0.03)	(0.09)	(0.14)	(0.57)	(0.20)	(0.22)	(0.01)	(0.32)	(0.39)

	Tin				Zinc					
	All regions	Asia	Americas	Europe	All regions	Asia		Americas		Europe
	LME	LME	LME	LME	LME	+SH	LME	+SH	LME	LME
Correlation	-0.19**	-0.15*	0.01	-0.11	-0.18**	-0.16**	-0.13*	-0.11	-0.12	-0.12
(p-value)	(0.01)	(0.08)	(0.87)	(0.17)	(0.02)	(0.04)	(0.08)	(0.14)	(0.11)	(0.12)

Note: The table presents the Spearman rank correlation between regional convenience yield and one month lagged inventory (both variables are month on month change in the monthly average). The p-value tests the null hypothesis = two variables are independent. ‘+SH’ implies LME plus SHFE warehouse inventory, ‘+COM’ implies LME plus COMEX warehouse inventory and ‘+SH+COM’ implies sum of the LME, SHFE and COMEX.

Although mixed results are obtained in the comparison between all regions combined and Asia, the empirical results in Tables 5 and 6 conclusively support our view that the supply/demand balance in Asia has a stronger influence than the other two regions, over the formation of base metal convenience yields⁴. This result is in line with our expectation as the demand of base metal in Asia has grown rapidly over the last few decades so the supply/demand environment in the region has a stronger impact on the base metal market than other regions. Our results thus support H1 (the Asian region is more informative than other regions) and partially support H2 (actual accessibility determines perceived supply shortage risk).

⁴ We obtained similar results and the same conclusion even when estimated premiums are applied in the estimation of convenience yields. The premiums are the costs that industrial users have to pay when they receive physical metals. The premiums are estimated by assuming that the premiums are determined in proportion to the price of each metal contract and the ratios are estimated from the data of premiums obtained from Bloomberg.

7. Concluding remarks

The aim of this study is to model the dynamics of the theory of storage using regional datasets. According to the fundamental notion of the theory of storage, the convenience yield is a negative function of inventory levels. A convenience yield reflects the value of benefit that can only be enjoyed by owning a physical commodity and such a benefit is exhausted over the period spanning the maturities of two contracts used to estimate the convenience yield. Thus, the assets stored in a distanced warehouse where a market participant at a given location cannot access them within the appropriate time frame should not have a major impact on the convenience yield perceived by the participants.

We estimate regional convenience yields for six major base metals using the options approach, and compare the regression analysis results of different regions. Our results support the hypothesis that Asia's supply and demand are more informative than those of other regions in determining convenience yield of base metals. Our results also partly support the hypothesis of actual accessible inventory determining perceived supply shortage of market participants. Furthermore, our findings indicate that the international base metal market is influenced to a great extent by Asian market participants at least during the period under consideration. Lastly, we demonstrate the applicability of the options-based approach in estimating the regional convenience yield of internationally traded commodities.

Our findings have practical implications to various stakeholders including market participants in a number of aspects. Base metal producers who are located outside Asia are better off observing the supply/demand condition in Asia instead of

their local market condition when they determine their inventory strategies. Since the convenience yield is a value awarded to the spot contract against the futures/forward contract, it equates the relative value of inventory and therefore the direction of convenience yield is of interest to the producers of base metals. Moreover, as it is evident that the Asian supply/demand condition has a stronger influence on the base metal market than other regions, speculators are expected to pay extra attention to the market sentiment in this region when they establish their trading strategies. While our study focuses on examining the notion of accessible inventory using the durable commodities, extending the study to non-durable assets including energy and agricultural commodities is expected to further strengthen this notion. Finally, we observe that some of the LME approved warehouses have periods with withdrawal constraints.⁵ This can be a limitation of our study as such a phenomenon may influence the relationship between convenience yields and inventory levels across regions.

⁵ There are LME approved warehouses including in the US, Malaysia and Europe where waiting time to withdraw metal exceeded 50 days during our sample period (Troszkiewicz and Kolesnikova, 2013).

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