Is the convenience yield a good indicator of a commodity's supply risk?

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Abstract

A strong increase in the demand for some commodities over the last decade will have a major impact on their future supply situation. Of increasing importance, therefore, is an assessment of a commodity's criticality, and especially its supply risk, by appropriate indicators. The literature has proposed numerous indicators of the supply risk. Here, we use the convenience yield of commodity futures as a supply risk indicator to address some of the major shortcomings of existing indicators, especially regarding their predictive power. This paper aims to test the applicability of the convenience yield as an indicator of a commodity's future supply risk. Therefore, we calculate historical convenience yields for 3-, 15-, and 27-month futures contracts for five major industrial metals (aluminum, copper, lead, nickel, and zinc) during the period 1999 to 2011. We compare the convenience yields at the beginning of the contract period to known indicators at maturity to find that the convenience yield has generally predictive power for the static stock lifetime (i.e., inventory volume/turnover) and future spot prices. Furthermore, we find that, with some restrictions, the convenience yield is an applicable indicator of a commodity's supply risk.

Keywords

Convenience Yield, Theory of Storage, Commodities, Supply risk indicators, Scarcity

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1 Introduction

Industrial metals are important basic materials for almost all industrial products, including cars and electronic devices. Hence, their demand is closely related to business cycles (Rosenau-Tornow et al., 2009). The production and consumption of industrial metals have increased sharply in the past decade, especially because of rapid growth in emerging markets. With an increasing number of fast-growing economies in other emerging countries, the availability risk of economically very important industrial metals, such as aluminum, copper, nickel, and zinc, can easily increase to a critical level in the future (European Commission, 2010). It is, therefore, increasingly important that manufacturers assess the future availability of commodities to avoid disruptions in the production process. With already low stock levels, particularly in the case of just-in-time production strategies, a short delay in supply can cause production disruptions and hence financial losses for a single company or for the economic system as a whole.

To assess commodity risks, it is important that we know the commodity's criticality, which we define, following Graedel et al. (2012), with the three dimensions supply risk, vulnerability to supply restrictions, and environmental implications. Each of these dimensions contains several components, quantified in turn by several indicators. The literature provides a variety of such indicators. Indicators of supply risk are, for example, the inventory level, the spot price, the Herfindahl-Hirschman Index, or the production volume (Rosenau-Tornow et al., 2009; Graedel et al., 2012). Good indicators should provide managers and policy makers with appropriate, easy, and continuously accessible information on supply risk. However, all of the existing indicators have shortcomings. For example, there is no indicator that is (a) available with a sufficiently high frequency (e.g., daily), (b) forward-looking to a certain extent, and at the same time (c) easily accessible to avoid delays due to data acquisition. To address these shortcomings, we propose the convenience yield, which is derived from the term structure of commodity futures as an indicator of supply risk. This yield can be interpreted as the benefit of having the commodity physically in stock (Copeland et al., 2004; Geman, 2005). Weymar (1966) theoretically demonstrated a negative relationship between these benefits, quantified by the convenience yield, and the current as well as future inventory level. The present paper aims to confirm empirically that the latter relationship can be used as a short- to medium-term forward-looking indicator of future supply risk, which avoids the shortcomings of existing indicators. Statistical tests are presented with convenience yields calculated from trading prices and inventory data of the London Metal Exchange (LME) for five major industrial metals (aluminum, copper, lead, nickel, and zinc) with different maturities (3, 15, and 27 months).

Our paper is structured as follows: We first introduce the underlying theory of commodity criticality, commodity futures, and the theory of storage. We then derive our hypotheses and explain the methodology. Next, we statistically test our hypotheses with historical convenience yields and analyze the ability of the convenience yield to serve as an indicator of a commodity's supply risk. Finally, we summarize the results of our empirical analysis and suggest avenues for further research.

2 Theory and Hypotheses

2.1 Criticality of Commodities and Supply Risk

The literature provides various approaches for the definition and designation of a commodity's criticality (see Erdmann and Graedel, 2011, for an overview of the most important studies concerning criticality of non-fuel minerals). According to Graedel et al. (2012), criticality comprises three dimensions: supply risk (risks that may at least lead to supply disruptions), vulnerability to supply restrictions (at a corporate, national, or global level), and environmental implications (environmental burden of a commodity caused, for example, by its toxicity or atmospheric emissions).

As the aim of our paper is to provide an indicator of future supply risk, we will focus on this dimension hereafter. The supply risk dimension consists in the medium term (5–10 years) of three components (Graedel et al., 2012): (1) geological, technological, and economic; (2) social and regulatory; (3) geopolitical. Several indicators quantify each component. Component (1) contains indicators of the time to depletion (e.g., reserves, production, and demand) and interdependencies with by-products. The development level and the impact of public policies on mining projects are included in component (2). Finally, indicators for the concentration of global production capacities (Herfindahl-Hirschman Index) and political stability (Worldwide Governance Indicator) are grouped in component (3).

Rosenau-Tornow et al. (2009) provided another approach to supply risk assessment, which is similar to the components approach of Graedel et al. (2012). They described supply risk using a framework of five so-called main indicators: (a) current supply and demand; (b) production cost; (c) geostrategic risks; (d) market power; and (e) (future) supply and demand trends. These main indicators include specific indicators, corresponding in part to those of Graedel et al. (2012). In particular, the main indicator "current supply and demand" includes the current market balance, calculated as the difference between supply, demand, and the change in the stock level. Market imbalances are as far as possible smoothed by additional supply from inventories or by building up stocks. However, this is only possible if the "stock keeping", which is a second indicator for this main indicator, is sufficiently high. Hence, for producers of industrial goods, a low inventory level bears considerable risk of a supply disruption in the short run if an excess demand occurs. Therefore, a measure for the inventory of a commodity is a very important short-term (<5 years) indicator in the supply risk dimension. In the Graedel et al. (2012) framework, this would be located in component (1) (geological, technological, and economic) in a short-term perspective.[1] We stress that in the Rosenau-Tornow (2009) approach "current market balance" and "stock keeping" are assessed by current values in conjunction with a qualitative outlook. However, for a manufacturer's assessment of the short-term supply risk, it would be interesting to also access more quantitative forward-looking data.

Another well-known approach is the cumulative availability curve, which accounts for dynamic effects (Yaksic and Tilton, 2009) but makes extensive use of data that are difficult to acquire. It incorporates as indicators a measure for the size of the reserves (or, where possible, the reserve base respectively the resources) and the price structure of their profitable exploitation. As it reflects depletion risk, it is mainly a long-term assessment tool containing geological, technological, and economic aspects.

[1]Note that Graedel et al. (2012) discuss the supply risk only from medium- and long-term perspectives with slightly different components, but the short-term perspective is not presented. They admit that individual indicators can be adjusted if necessary. Hence, users can be provided this way with a broad short-term perspective.

To sum up, one can see that a variety of indicators for measuring supply risk was discussed in the literature. However, we notice a lack of feasible indicators of short-term supply risk. For a short-term perspective, it is important that we have an indicator with a sufficiently high frequency (e.g., daily) so that shifts in the supply situation are visible immediately. Furthermore, it should be forward looking to a certain extent to allow managers to initiate countermeasures in advance. Finally, the data should be easily accessible so that new information is available quickly.

To close this gap in the literature, we analyze the convenience yield (i.e., the benefit derived from having the commodity physically in stock) of commodity futures as an indicator of future supply risk. We draw on the extended theory of storage from Weymar (1966), which states that this quantity is related to future inventory levels (see next chapter). The convenience yield, as a forward-looking indicator for supply risk, would be accessible easily from futures trading prices with daily frequencies as many commodity futures with different delivery dates are traded daily on international stock exchanges.[2]

2.2 Commodity Futures and Convenience Yields

Forward curves of commodity futures exhibit a variety of different shapes. One of their main features is the slope of the curve, which largely determines whether the future price is above or below the current spot price. Of particularly significance, from a financial economics perspective, is the negative slope of this curve, which is termed backwardation (i.e., shorter-dated contracts have a higher price than longer-dated ones). This is a major difference compared to futures on financial assets (e.g., stocks and bonds). For example, futures on stocks that pay no dividend, and hence generate no direct cash flows like commodities, exhibit a positive slope. Therefore, a suitable explanation for negative slopes of forward curves has to be found.

The future price, F_{tT}, at time t for the delivery of a commodity at time T can be calculated from arbitrage arguments by a cost-of-carry valuation formula. In general, F_{tT} equals the spot price, S_t, plus the cost of carrying the underlying asset until the maturity of the contract. Furthermore, the benefits for the holder of the commodity until maturity have to be deducted. In its continuous form, the cost-of-carry pricing formula of a commodity future can be expressed as follows:

$$F_{tT} = S_t e^{(r_{tT} + c_{tT} - CY_{tT})(T-t)} \tag{1}$$

The cost of carry consists of the cost of capital, which can be calculated using the interest rate, r_{tT}, and the cost of storage rate, expressed as c_{tT}, which covers all expenditures for storing the commodity (e.g., warehouse rent or insurance fees). The residual between the observed future price and the spot price plus the cost of carry is captured in the convenience yield, CY_{tT}, in the form of a rate, which allows future prices below the current spot price.

It is analogous to the dividend yield in the price of a stock future and quantifies the income for the owner of the underlying commodity. As commodities usually do not generate direct cash flows (except in the case of gold, where leasing contracts can provide an income for the owner), the income has to be interpreted as a benefit of physically holding the commodity. It can be seen as a “flow of services” (Brennan and Schwartz, 1985) or a “liquidity premium”,

[2] We wish to point out that our analysis does not necessarily require a completely weak or semi-strong form of commodity market efficiency (Fama, 1970, 1991). It is only required that market prices reflect the equilibrium from supply and demand, which appears to be a reasonable assumption for LME prices.

which the owner of a resource receives until maturity (Copeland et al., 2004). Hence, a positive convenience yield reduces the future price, which explains backwardated forward curves.

The widely accepted theory of storage tries to interpret the convenience yield and the related benefits. The development of the theory of storage goes back to the first half of the 20^{th} century (Working, 1927, 1933, 1934, 1948, 1949; Kaldor, 1939). The case of industrial metals particularly illustrates the economic meaning of this flow of services. The owner of the commodity, who is free to consume it until maturity, is prepared for unexpected shortages in supply or increases in demand (Fama and French, 1987). For example, a producer of industrial goods can avoid a disruption in the manufacturing process by having the commodity in a warehouse. The value of this benefit is inversely related to the inventory level. It is especially high, if inventories are low and purchasers are forced to secure a short-term supply. For a more detailed explanation of the development of the theory of storage, we refer to a recent article of Geman and Smith (2013) in this journal. Several contributions - for example, Brennan (1958) and Telser (1958) - used the current inventory level as a proxy for the convenience yield, confirming the theory of storage for some agricultural commodities. Brennan (1991) found evidence of an inverse relation between the convenience yield and the level of inventories for precious metals, oil, lumber, and plywood. Furthermore, Pindyck (2001) analyzed the short-run dynamics of commodity spot and future markets. He thus showed, for crude oil, heating oil, and gasoline, that forward curves are backwardated and that the variation in the convenience yield corresponds to unpredictable temporary supply or demand fluctuations. Moreover, he showed a positive correlation between the convenience yield and the spot price at the same point of time. He explained this by the fact that unusually high spot prices are often induced by temporary shifts in supply or demand. In such situations, a high demand for inventories, and thus a high convenience yield, is observed as inventories can be used for the reallocation of production across time. Heaney (2002) provided a simple trading strategy to approximate the impact of convenience yields on futures prices for copper, lead, and zinc. He concluded that the convenience yield approximation is both statistically and economically important to explain the variation between futures prices and spot prices. In a later contribution, Heaney (2006) showed that the convenience yield is a decreasing, nonlinear function of the stock level. The energy commodities oil and natural gas were further examined by Geman and Ohana (2009). They found dependencies of the convenience yield on the inventory level for both commodities. As natural gas showed a seasonal behavior in its stockpile, the results were even more accurate for a detrended inventory measure. According to these studies, the convenience yield is expected to be high in the case of low stocks, and vice versa, which is in line with the theory of storage. For LME metals, Geman and Smith (2013) found a negative relationship between an interest-adjusted spread, which is similar to the convenience yield, and the current inventory level normalized to the world consumption volume.

Other publications tried to justify the existence of the convenience yield and their dependence on inventory levels with theoretical models. The relationship between higher current inventory levels and smaller convenience yields (and vice versa) was shown by, for example, Heinkel et al. (1990) by means of a three-date model. Additionally, he found with his model that the convenience yield increases with higher marginal production costs and decreases as correlations between the spot price of the commodity increase. Litzenberger and Rabinowitz (1995) showed that the intrinsic option value of oil reserves in the ground, which increases with commodity price risk, can explain backwardation. Routledge et al. (2000) showed with an equilibrium model that, for low inventories and at the same time high net consumption demand, forward prices are backwardated, which implies positive convenience yields.

In addition to these studies, Weymar (1966) showed theoretically that convenience yields should also depend on the expected future stock level of a commodity. He also found the first empirical evidence in the behavior of cocoa prices for this relationship. To the best of our knowledge, further empirical studies on the predictive power of convenience yield have not been conducted so far. Further study seems to be desirable, particularly for practical applications, as this yields the opportunity to obtain a forward-looking indicator for supply risk. An empirical test of the validity of this theoretical relationship is given below.

To give a comprehensive overview of the literature of commodity futures prices, we also want to mention the theory of normal backwardation, which also tries to explain backwardation in future prices (Keynes, 1923, 1930). In this model, the future price is equal to the expected spot price in the future plus a risk premium. Keynes argued that hedgers (e.g., commodity producers) are willing to sell their products in the futures market for a price below the expected spot price in the future. The price difference is a risk premium, which speculators charge for bearing the price risk. However, despite the usefulness of this theory for several commodities, many studies cast doubts on the validity of this interpretation of the future price for industrial metals (Chowdhury, 1991; Watkins and McAleer, 2006; Otto, 2011). Hence, we focus on the theory of storage in the following text.

2.3 Hypothesis

As shown above, convenience yields are driven by the benefit of physically holding the commodity and thus by the liquidity premium or a flow of services. According to existing research, the convenience yield increases with a declining stock level, and therefore with the commodity's supply risk (Brennan, 1958; Fama and French, 1988). As Fama and French (1987) showed, this is the case where a commodity is an input for production or it needs to be held in inventory to meet unexpected demand (particularly for strategic commodities). From the perspective of a manufacturer who holds a futures contract, the supply risk of the commodity in the future is also of great relevance. Indeed, Weymar (1966) showed that the convenience yield should also depend on the inventory level in the future. This leads to the hypothesis that a high convenience yield is an indicator of a high supply risk for the commodity up to the futures maturity, and vice versa.

Therefore, our hypothesis is as follows:

If the convenience yield of a futures contract is high, then the supply risk until the maturity of the contract is high, and vice versa.

To operationalize this hypothesis, we first focus on predicting an inventory measure in the sense of Weymar (1966). As high supply risk would be related to a low level of the inventory measure we expect the convenience yield to be high if the inventory measure is low. Instead of using the absolute inventory level as a measure, we argue that it has to be set in the context of the turnover rate.[3] In particular, examining a time series over a period of several years, one finds long-term trends in inventory levels, resulting from changes in demand, for example, from developing countries. Furthermore, the inventory level at a given time can be used to predict future inventory levels because of the high autocorrelation between inventory time series, due to an autoregressive process. Hence, it can be expected that, according to the classical theory of storage, we should be able to use the convenience yield to predict future inventory levels because of its time series properties. Therefore, we define the static lifetime

[3] Note that Geman and Smith (2013) also normalize the inventory data. They use the world consumption volume as a reference quantity.

of inventory as the quotient of the inventory level and the turnover rate of a commodity. We use the static lifetime to avoid possible biases in our analysis as mentioned above.

Comparing the convenience yield to the static lifetime until the contract's maturity, we examine whether it is a predictor of the future static lifetime of a commodity's supply risk (i.e., a negative relationship between convenience yield and static lifetime). We refer to this version of our hypothesis as H1. As in the classical theory of storage, there could be an inverse relationship between the convenience yield and the static lifetime of inventories. This makes sense if one considers that the marginal benefit of an additional unit of inventory (and hence of the static lifetime) decreases with higher inventory levels (Brennan, 1958; Fama and French, 1988). As our chief concern is the static lifetime dependency on the convenience yield, we define a marginal static lifetime as the first derivative of the static lifetime on the convenience yield, which should be a decreasing function of the convenience yield.

As the spot price of a commodity is also referred to in the literature as an indicator of a commodity's supply risk (Krautkraemer, 1998), we further investigate the predictive power of the convenience yield on future spot prices. This is supported by earlier findings that showed higher returns of diversified commodity future portfolios, in which commodity futures with high convenience yields are overweighted (Rallis et al., 2012). Therefore, we propose high convenience yields, as an indicator of supply risk, can predict higher spot prices at maturity. We test this relationship as version H2 of our hypothesis.[4]

In the following section, we derive appropriate regression models to test our hypothesis.

3 Methodology

To test the hypothesis, we calculate the convenience yield by solving equation (1) for CY_{tT}:

$$CY_{tT} = r_{tT} + c_{tT} - \frac{1}{(T-t)} \ln\left(\frac{F_{tT}}{S_t}\right) \qquad (2)$$

To test H1, we apply two different test models with different operationalizations. First, we follow the argument of Weymar (1966) and test the predictive power of the convenience yield, CY_{tT}, at time t on the static lifetime of inventory until the maturity of the contract, T. As a proxy for the inventory, we use the average static lifetime, $\overline{SLT_T}$, from t until T. For an insight into the time dependence of the predictive power, different times to maturity are tested. In the first step, we apply a simple but robust linear regression model to check the relationship. The error term is expressed by e_t and is assumed to be normally distributed:

$$\overline{SLT_T} = \alpha_1 \cdot CY_{tT} + \alpha_2 + e_t \qquad (3)$$

An exponential model that reflects the dependency of the marginal change in inventory on the convenience yield is presented below as a robustness check.

In our second model, we test for an inverse relationship, using the static lifetime, SLT_T, at the maturity of the contract instead of the average static lifetime. We define the future static lifetime of stocks as a function of the inverse convenience yield, CY_{tT}, at the beginning of the contract's lifetime t:

[4] We note that efficient spot markets should offer no possibility to gain trading profits from forecasts of future spot prices from past prices.

$$SLT_T = \beta_1 \cdot CY_{tT}^{-1} + e_t \qquad (4)$$

The advantage of this approach is that we look at the static lifetime 3 to 27 months ahead. These static lifetimes are far less influenced by those at time *t* due to possible autocorrelation (see robustness checks). Therefore, we avoid strong influences from the known relationship between inventory and the convenience yield, as predicted by the classical theory of storage mentioned above.

This second model, shown in equation (4), assumes that the marginal static lifetime is a decreasing function of the convenience yield. This yields an inverse relationship between the convenience yield and the static lifetime at a given point in time, which is analogous to the relationship between convenience yields and inventories according to the classical theory of storage (Brennan, 1958; Fama and French, 1988). This approach also seems to be appropriate as the static lifetime approaches zero with an increasing convenience yield. From an economic point of view, this makes sense, as the flow of services of an additional unit of the static lifetime is most valuable when its absolute value is low. We also tested a linear regression model for SLT_T, which is not reported in this paper as it yielded similar results. By choosing equations (3) and (4), we aim to present results from different models (linear and inverse) to underline the robustness of our conclusions.

The coefficient β_1 will be estimated in the following regression analysis from the static lifetime of commodity stocks at the end of the commodity futures lifetime and the convenience yield at the beginning of different maturities. As in some cases the convenience yield calculated from equation (1) takes on economically implausible but usually small negative values[5], the data need to be rescaled to conduct the regression, using equation (4). Therefore, a constant term is added to the convenience yield so that the smallest value of each time series is equal to zero. As a result of this rescaling, all values of the exogenous variable, $1/CY_{tT}$, are larger than zero (the smallest value has to be omitted as division by zero is not possible).

To test H2, we express the logarithmic spot price, $ln(S_T)$, at the maturity of the futures contract as a function of the futures' convenience yield, CY_{tT}, at the beginning of the contract's lifetime, *t*, and the normally distributed error term, e_t:

$$\ln(S_T) = \gamma_1 \cdot CY_{tT} + \gamma_2 + e_t \qquad (5)$$

The data sources for testing the regression models are presented in the next section.

4 Data Sources

To test the hypotheses with the above-mentioned regression models, we use time series data with daily frequencies for aluminum, copper, lead, nickel, and zinc. The data for the spot and futures prices, as well as inventory and turnover, are retrieved from the London Metal Exchange, which is one of the leading markets for industrial commodities worldwide. The descriptive statistics of these time series are presented in Table 1. LME inventory levels of these commodities can amount, on average, to about 2–3% of the annual world production (except for lead, which amounts to less than 0.1%). As the LME network has more than 600 warehouses in Europe, USA, and Asia, we assume their inventory, prices, and turnover are

[5] A negative convenience yield would enable market participants to realize risk-free arbitrage profits by buying the commodity in the spot market and taking on a short position in commodity futures. The profit generated with this trading strategy exceeds the cost of carrying the commodity until the maturity of the futures contract.

representative of the world market for the respective commodities. In our analysis, we use cash and futures prices of aluminum, copper, lead, nickel, and zinc with daily frequencies from January 4, 1999, to March 5, 2011. The maturities of the contracts are 3, 15, and 27 months (M) (for lead, only 3M and 15M data are available with a sufficiently long-term record), and the price quotation is in US$ per metric ton (MT). Contracts with 3-month maturities are settled on a daily basis, whereas e.g. for 15M and 27M contracts, the settlement date falls normally on the third Wednesday of every month. As the time series are for constant maturities, we can assume in our analysis that 15M and 27M contracts are settled on a daily basis as well. The five metals were chosen because of their economic importance in many sectors, for example, electronic and automotive industries. In addition, the supply situation of aluminum, copper, nickel, and zinc can become unsecure in the future (European Commission, 2010).

To estimate storage costs, we draw on LME warehouse rents, which are determined for one year on the basis of a fixed amount of US cents/MT/day and are specific to a commodity.[6] We calculate the storage cost rate by relating the rental fee to the daily spot prices and transform this value into a continuous rate. We obtained average rates between 0.5% and 2.5% p.a., depending on the price of the commodity (more expensive commodities showed lower rates and vice versa).

The descriptive statistics (Table 1) of the convenience yields, calculated using equation (2), reveal that the yields, in general, increase with the futures' time to maturity, as indicated by the averages and medians. Furthermore, we observe that the standard deviation decreases with the time to maturity. This is in line with the Samuelson effect, which predicts decreasing volatility of futures prices with increasing time to maturity (Samuelson, 1965). This also explains the increasing minimum and the decreasing maximum values of the yield series. For all commodities, we observe negative minimum values for the convenience yields. Compared to the maxima, their absolute values are much smaller, although they are economically implausible. We calculated the percentage of convenience yield values below -5% and obtained for the 3 months yields the following percentages of the observed values: Aluminum 7.4%, copper 0.0%, nickel 0.4%, lead 9.2% and zinc 13.0%. For aluminum 15M and 27M we calculated 5.3% and 2.4%, for 15 months Zinc 0.2%. In all other cases, no yields below the threshold occurred. Part of these negative values can be explained by a period of strong negative values during the financial crisis, when spot prices dropped sharply and futures prices took some time to adapt. Furthermore, we neglect any kind of additional cost related to storing the commodity, such as insurance premia or transportation costs, which might also partially explain the negative convenience yields. According to Tilton et al., (2011), phases with negative convenience yields lead to strong contango in the forward curve.

To test the hypothesis with the static lifetime of stocks, we also use daily data of total stock keepings (in MT) in the LME warehouse network for these commodities. Furthermore, we use the daily turnover (converted to MT/day) at the LME to calculate the static lifetime of the inventory as the quotient of the inventory over the turnover. To convert the unit of turnover from number of contracts/day to MT/day, we multiply the daily turnover of each commodity by the contract size: 6 MT for nickel and 25 MT for other commodities.

The descriptive statistics in Table 1 show an average static lifetime of stocks between 0.3 and 0.7 days for all commodities other than lead. Lead has a very low average static lifetime: only 0.003 days. Minimum lifetimes are usually around one order of magnitude below the average values. Maximum values are less reliable as they are pushed up by days with extremely low turnover rates, explaining results of tens to hundreds of days. These values are actually one-

[6] We gratefully acknowledge these data provided to us by the LME.

time occurrences. All data mentioned above are sourced from the Thomson Reuters Datastream, except for warehouse rent, information on which is kindly provided by the LME.

As a risk-free daily interest rate, we use US treasury yields on actively traded non-inflation-indexed issues, adjusted to constant maturities (in US$). The bond maturities were 3, 12, 24, and 36 months. To approximate the risk-free rate for 15M and 27M futures, we interpolated between the next longer and shorter maturities (e.g., to approximate the 15-month rate, we interpolated between 12 and 24 months). The data are retrieved from the Federal Reserve System website. These interest rates are discrete. Since the convenience yield is based on a continuous formula, the discrete interest rates are transformed to continuous interest rates.

Table 1: Descriptive statistics of data for the convenience yield time series for futures maturities of 3, 15 and 27 months (M), the static lifetime of stock level, and the LME spot prices

		Convenience yield 3M [% p.a.]	Convenience yield 15M [% p.a.]	Convenience yield 27M [% p.a.]	Static stock lifetime [days]	Spot price [$/MT]
Aluminum	Average	0.495	3.433	4.400	0.692	1876.91
	Median	–0.525	3.280	4.150	0.375	1703.38
	Standard deviation	5.080	5.041	4.699	9.604	519.04
	Minimum	–10.540	–7.710	–6.300	0.043	1136.20
	Maximum	28.660	16.600	15.510	541.804	3271.25
Copper	Average	4.854	6.695	7.269	0.346	4127.91
	Median	1.755	3.440	4.840	0.158	3184.00
	Standard deviation	7.867	7.149	6.191	1.371	2613.05
	Minimum	–5.240	–2.500	–1.940	0.012	1318.25
	Maximum	35.630	28.960	22.510	56.602	10179.50
Lead	Average	4.174	6.345	–	0.003	1197.65
	Median	1.120	3.770	–	0.002	949.00
	Standard deviation	9.251	7.087	–	0.017	823.73
	Minimum	–10.940	–4.730	–	0.000	400.75
	Maximum	47.630	33.140	–	0.941	3989.00
Nickel	Average	6.221	9.048	9.470	0.369	15581.37
	Median	2.550	6.405	7.060	0.286	13286.50
	Standard deviation	9.651	8.386	7.462	0.280	9894.73
	Minimum	–6.930	–4.280	–3.080	0.024	3877.50
	Maximum	69.880	40.760	34.910	3.581	54050.00
Zinc	Average	–0.157	3.886	5.420	0.620	1626.06
	Median	–1.475	1.831	3.265	0.394	1191.75
	Standard deviation	5.049	6.297	6.352	1.759	902.45
	Minimum	–14.850	–5.961	–4.420	0.017	722.75
	Maximum	34.150	24.696	26.800	40.710	4603.00

5 Tests and Results

5.1 Test of Hypothesis Version H1

The H1 test results based on the linear regression model from equation (3) and the average static lifetime, $\overline{SLT_T} = \alpha_1 \cdot CY_{tT} + \alpha_2 + e_t$, are presented in Table 2. In all cases other than lead, we obtain highly significant negative values for the α_1 coefficient, as expected. According to the regression model, this means the average static lifetime of stocks decreases with an increasing convenience yield. For lead, we obtain very low but positive results. The explanatory powers of regression lie in a range between 0.272 and 0.379 for copper, nickel (except for 27M with 0.083), and zinc (except for 3M with 0.18). For aluminum, we obtain an explanatory power of 0.110 and below for all cases.[7]

[7]The results are checked for heteroscedasticity by a Levene test, which rejects the null hypothesis of homoscedasticity for all cases other than the 3M lead and 27M zinc time series. We also test our data for autocorrelation of residuals and find a positive autocorrelation in all cases. This can be due to the moving average of static lifetime constructed. It disappears in most cases when only the lifetime at maturity is used. Furthermore, non-linearity in the data can also explain the autocorrelation. We calculate t-values of the regression coefficients with Newey-West robust standard errors with a lag number equal to the fourth root of the sample size.

Table 2: Predictive power of a futures contract's convenience yield on the average static lifetime of the underlying commodity's inventory level during the lifetime of the contract. Values for the regression coefficients α_1 and α_2 and explanatory power, R^2 (values in brackets are the t-values calculated with Newey-West robust standard errors; ***significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level).

	3M			**15M**			**27M**		
	α_1	α_2	R^2	α_1	α_2	R^2	α_1	α_2	R^2
Aluminum	–0.040***	0.714***	0.027	–0.042***	0.856***	0.110	–0.033***	0.878***	0.070
	(–5.741)	(10.566)		(–8.641)	(23.970)		(–6.490)	(24.110)	
Copper	–0.026***	0.475***	0.272	–0.030***	0.561***	0.362	–0.032***	0.613***	0.366
	(–12.358)	(18.423)		(–14.422)	(19.778)		(–16.720)	(21.363)	
Lead	0.000	0.003	0.001	0.000***	0.003***	0.094	–	–	–
	(0.779)	(20.309)		(5.074)	(34.569)				
Nickel	–0.015***	0.459***	0.379	–0.014***	0.481***	0.355	–0.007***	0.390***	0.083
	(–11.256)	(32.4921)		(–11.237)	(26.597)		(–4.616)	(18.282)	
Zinc	–0.055***	0.615***	0.179	–0.043***	0.828***	0.281	–0.040***	0.923***	0.285
	(–7.225)	(19.894)		(–13.332)	(23.374)		(–15.047)	(27.398)	

Table 3 presents H1 test results based on equation (4): $SLT_T = \beta_1 \cdot CY_{tT}^{-1} + e_t$, where the static lifetime at maturity is the endogenous variable. All contracts for all commodities show a positive β_1 coefficient, as expected from the theory. According to equation (4), this again means that a high convenience yield at the beginning of a contract's lifetime corresponds to a low static lifetime of stocks at the contract's maturity, and vice versa. The statistical significance of the results depends on the time to maturity of the respective contract.[8] For a 3M contract, β_1 is statistically significant for all commodities. Futures with a 15M maturity show significant results for all contracts except aluminum and lead, while 27M contracts produce significant results for only nickel and zinc.[9] Even though the β_1 value is not clearly dependent on the time to maturity for every single commodity, it can generally be stated that β_1 is larger for shorter than longer maturities. However, it has to be noted that this does not hold strictly for all commodities. Version H1 of our hypothesis can be accepted in general on the basis of these results, even though the significance of the results decreases with increasing time to maturity.

Table 3: Predictive power of a futures contract's convenience yield on the static lifetime of the underlying commodity's inventory at the date of maturity. Values for the regression coefficient β_1 are presented (values in brackets are the t-values calculated with Newey-West robust standard errors or, where appropriate, with the ordinary least squares standard errors indicated with ^{OLS}; ***significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level).

	3M	**15M**	**27M**
Aluminum	4.033***	0.097	0.866
	(3.483)^{OLS}	(0.666) ^{OLS}	(1.373) ^{OLS}
Copper	2.243***	0.148***	0.013
	(9.479)	(4.011) ^{OLS}	(0.877) ^{OLS}
Lead	0.017***	0.001	-
	(7.387) ^{OLS}	(1.818) ^{OLS}	
Nickel	1.871**	2.040***	0.746*
	(2.782)	(4.920)	(2.248)
Zinc	8.528***	2.229***	2.453***
	(13.759)	(3.115)	(3.784)

5.2 Test of Hypothesis Version H2

Version H2 of our hypothesis is tested with equation (5): $\ln(S_T) = \gamma_1 \cdot CY_{tT} + \gamma_2 + e_t$. The regression results are listed in Table 4. The data show that there exists a positive relationship between the convenience yield today and the spot price at the futures contract maturity in many cases. This means that high convenience yields predict high spot prices, and vice versa. The coefficient γ_1 is positive and statistically significant for all commodities with 3- and 15-month maturities, except for 3M aluminum and 15M nickel. For 27M maturities, positive values are obtained for copper and zinc, but only copper is statistically significant. Aluminum

[8]A test for heteroscedasticity reveals that the null hypothesis of homoscedasticity cannot be rejected for aluminum, lead, and copper (15M and 27M) time series with a 10% significance level. In the other cases, we find evidence of heteroscedasticity. Nickel and zinc are consistently heteroscedastic. Furthermore, we test the residuals for autocorrelation with a Durbin-Watson test, finding autocorrelation only in the three nickel time series. Hence, *t*-values are calculated with OLS standard errors if the residuals are homoscedastic and not autocorrelated. In all other cases, Newey-West robust standard errors are used with a lag number equal to the fourth root of the sample size.

[9]R^2 values are not presented here as they are misleading for regression models without a constant term.

and nickel show negative coefficients, but none of them is significant. Hence, version H2 can be accepted for 3- and 15-month futures as well as for 27M copper.[10]

[10]We find heteroscedastic residuals in all cases except for 3M aluminum and autocorrelation for all time series. Hence, *t*-values are calculated with Newey-West robust standard errors with a lag number equal to the fourth root of the sample size.

Table 4: Regression of logarithmic spot prices at maturity on convenience yields 3, 15, and 27 months (M) prior. Values for the regression coefficients γ_1, γ_2 and explanatory power, R^2 (values in brackets are the t-values calculated with Newey-West robust standard errors; ***significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level).

	3M			**15M**			**27M**		
	γ_1	γ_2	R^2	γ_1	γ_2	R^2	γ_1	γ_2	R^2
Aluminum	0.002	7.514***	0.001	0.016***	7.472***	0.095	–0.001	7.563***	0.001
	(0.629)	(537.264)		(5.184)	(415.148)		(–0.374)	(355.929)	
Copper	0.026***	8.000***	0.100	0.045***	7.865***	0.262	0.058***	7.778***	0.334
	(7.736)	(193.654)		(13.630)	(161.768)		(15.719)	(145.561)	
Lead	0.016***	6.811***	0.047	0.035***	6.697***	0.145	–	–	–
	(5.267)	(167.993)		(8.734)	(135.050)				
Nickel	0.011**	9.426***	0.030	0.004	9.512***	0.003	–0.005	9.660***	0.003
	(2.866)	(278.300)		(1.001)	(223.395)		(–1.135)	(185.758)	
Zinc	0.052***	7.267***	0.269	0.029***	7.174***	0.135	0.001	7.323***	0.000
	(6.652)	(327.540)		(8.663)	(240.999)		(0.335)	(190.564)	

5.3 Robustness Check

5.3.1 Test of the statistic regression models

As a robustness check for the regression models, we compare the static lifetime means of two subsamples from our datasets and check for significance of their difference. H1 results with average static lifetime and lifetime at maturity are presented in Table 5 and Table 6. For the test, we divide the datasets of static lifetime of stocks into two subsamples, depending on the value of the corresponding lagged convenience yield. The first sample contains all data points with $CY_{tT} \leq \bar{r}_{tT} + \bar{c}_{tT}$ and the second, all points with $CY_{tT} > \bar{r}_{tT} + \bar{c}_{tT}$, where $\bar{r}_{tT}$ and $\bar{c}_{tT}$ are the average values over the specific contract period. We calculate the differences between the two subsample means and check their significance with a Wilcoxon rank sum test (not reported here) in addition to a t-test. As the first groups contain lower convenience yields, they should have a higher average static lifetime of stocks, according to H1. Therefore, the differences between the mean values are expected to be positive.

Table 5: t-test for the predictive power of convenience yields on future average static lifetime of inventories during the time to maturity of the futures contracts. The data set is separated into two subsamples, contango and backwardation (*significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level).**

	3M	**15M**	**27M**
Aluminum	0.412***	0.341***	0.113***
Copper	0.434***	0.408***	0.307***
Lead	0.000***	–0.001***	–
Nickel	0.300***	0.345***	0.138***
Zinc	0.515***	0.510***	0.374***

The robustness check of the model for the average static lifetime until maturity (Table 5) fully supports the regression results. We obtain highly significant differences in all cases. For lead, we obtain no difference or a negative difference, both consistent with the regression results that rejected H1. The Wilcoxon rank sum test supports the results in all cases, including also lead.

Table 6: t-test for the predictive power of convenience yields on future static lifetime of inventories at the maturity of the futures contracts. The data set is separated into two subsamples, contango and backwardation (*significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level).**

	3M	**15M**	**27M**
Aluminum	0.402***	–0.043***	–0.285***
Copper	0.428***	0.177***	–0.043***
Lead	0.000***	0.000***	–
Nickel	0.280***	0.358***	0.085***
Zinc	0.517***	0.163***	–0.011***

The differences in mean values of static lifetime at maturity also confirm H1 for all commodities, except lead, 27M copper, and zinc contracts, as well as 15M and 27M aluminum contracts (Table 6). The Wilcoxon rank sum test, not reported here, also fails to confirm the H1 results for lead and 27M copper futures. These checks support the regression results obtained from equation (4) with the inverted model in general. In the case of lead, they do not support the regression results, which led to an acceptance of H1 for 3M contracts. In addition, the differences in means yield negative values for 15M and 27M aluminum futures, as well as for 27M copper. None of the three data sets yields significant results in the regression model, even though the regression parameters have the correct sign. Only in the case of the 27M zinc contract are the results of the regression model contradicted by the robustness check. In summary, 3M lead is the only significant regression result that is not supported, and 27M zinc the only one that is contradicted. Overall, these additional tests support the regression results and show that the model is quite robust.

Furthermore, we check the relationship between the average static lifetime until time of maturity and the convenience yield at the beginning of the contract's lifetime for the marginal variation with increasing convenience yields. The static lifetime should decrease with a decreasing rate because one additional unit of static lifetime yields a higher benefit at low levels compared to higher levels. To include negative values of the convenience yield (which are economically not plausible), we introduce an exponential regression model, $\overline{SLR_T} = \tau_2 e^{\tau_1 CY_{tT}} + e_t$, with the regression coefficients τ_1 and τ_2 (detailed results are not reported here). Similar to the results of the linear regression model from equation (3), we obtain a negative slope of the fit curve, except in the case of lead. All coefficients are again highly significant. In addition, in all cases other than 27M nickel, we obtain much higher explanatory powers compared to the simple linear model presented above (for 27M nickel the difference is very small). This result confirms that our approach yields differences in the marginal rate of change of the static lifetime, as predicted by the theory of storage. However, we obtain very robust results with the linear as well as the exponential model.

In addition, we test the robustness of the regression results for H2. To do so, we again calculate the differences in means of the dependent variable from two subsamples, grouped once again according to $CY_{tT} \leq \bar{r}_{tT} + \bar{c}_{tT}$ and $CY_{tT} > \bar{r}_{tT} + \bar{c}_{tT}$ (see above). From H2, we expect negative differences in our analysis as group one, with lower convenience yields, is expected to be related to lower logarithmic prices. The t-test supports H2 in all cases at a highly significant level, with two exceptions (Table 7): the 3M and 15M nickel tests yield positive values. A Wilcoxon rank sum test, not reported here, leads to the same results. In summary, the test fully supports the significant results of the regression model for 3 and 15 months, with the exception of nickel and 27M copper. The test even yields negative and significant results for aluminum and zinc. In the case of nickel, the robustness check yields results with different signs than the regression model. The model supports acceptance of H2 only for 27M nickel, previously rejected by the regression test. In general, the robustness checks for H2 also support our regression analysis results very well.

Table 7: t-test for the predictive power of convenience yields on future spot prices. Differences between subsamples, contango, and backwardation (*significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level)**

	3M	**15M**	**27M**
Aluminum	–0.034***	–0.228***	–0.049***
Copper	–0.561***	–0.537***	–0.587***
Lead	–0.295**	–0.489***	–
Nickel	0.022***	0.044***	–0.159***
Zinc	–0.683***	–0.295***	–0.026

5.3.2 Test for operationalization-induced biases

As stated above, the classical theory of storage explains the dependency between convenience yields and inventory at a given date. According to the classical theory of storage, a high convenience yield is related to a low inventory level, and vice versa. As inventory levels usually show a high degree of autocorrelation, they predict future inventory levels to a certain degree.[11] Hence, it is possible to have, for example, a high convenience yield and low inventory today and, at the same time, low inventories at maturity. This does not actually imply that a high convenience yield is a good predictor of low inventories in the future. With the autocorrelation of inventory levels, future inventory levels are to a certain degree determined by today's inventory.

Nevertheless, we test our hypothesis with the static lifetime of stocks, which we assume is not autocorrelated. However, as the static lifetime is linearly dependent on the inventory level, this approach has to be challenged. To do so, we test the static lifetime for autocorrelation. We calculate the correlation between the static lifetimes of one commodity with different time lags. Thus, we test for correlation between the static lifetime at the beginning and at the maturity of different futures contracts. Thereby, we aim to eliminate the influence on our regression results of the classical theory of storage. We test time lags of 3, 15, and 27 months, corresponding to the maturities of the futures. The results are presented in Table 8.

Table 8: Autocorrelation coefficients for the static lifetime time series with 3-, 15-, and 27-month time lags (*significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level)**

	3 months	**15 months**	**27 months**
Aluminum	0.001	0.000	–0.001
Copper	0.056**	0.024	0.002
Lead	0.003	–0.002	–
Nickel	0.680**	0.387**	0.101**
Zinc	0.077**	0.039*	0.015

The results show in general very low correlation coefficients (0.077 or less) for all commodities other than nickel, which are not significant in most cases. For nickel, the correlation coefficients are significant and much higher, with values ranging from 0.680 (for 3M) down to 0.101 (for 27M). From these findings, it seems unlikely, except for nickel, that the results of regression models (3) and (4) are due to the autocorrelation effects of inventory levels. For nickel, these effects could yield very robust results, especially for 3- and 15-month maturities. The autocorrelation coefficient for the 27M maturity, at 0.101, is not very strong, so we assume the regression result is not purely attributable to this factor. In summary, the autocorrelation test supports the results from the regression model, as it excludes autocorrelation effects of the classical theory of storage in most cases, and therefore validates our approach. In addition, we tested the static lifetime time series for a unit root with an Augmented-Dickey-Fuller test (results not reported here). Based on this, we can reject the unit root null hypothesis for the plain SLT_T time series, as well as the 3-month $\overline{SLT_T}$ average time series, at the 0.1% significance level, which further justifies the use of static lifetime of stocks rather than the inventory level.

Furthermore, we check the robustness of the results for hypothesis H2 concerning operationalization-induced biases. To test H2, we relate the convenience yield to the spot price of the commodity at the futures contract maturity. The regression results might have been influenced by long-term price trends, possibly due to inflation or other fundamental effects such as increasing production costs over time. Hence, the significant relationship between the variables might be due to a long-term effect, and not the actual supply risk of the commodity. To test the robustness of our results for such long-term effects, we check the predictive relationship between the convenience yield and relative prices at the maturity of

[11]We found high autocorrelation coefficients of up to 0.98 for time lags of 3 months, and up to 0.24 for 27M.

futures contracts. We assume relative prices are free of long-term price trends (e.g., due to inflation or overall increases in commodity production costs).[12] We therefore divide the commodity spot prices by the value of the CRB BLS Metals Sub-Index on the same day to obtain the relative price development of the spot prices to an index. The relationship is checked with the following regression model:

$$\ln(s_T) = \varphi_1 \cdot CY_{tT} + \varphi_2 + e_t \qquad (6)$$

Thus, s_T is the relative price at the time of maturity T. φ_1, and φ_2 are regression coefficients, and e_t is an error term. The results are shown in Table 9.

Analogous to the regression of the future spot price on the convenience yield, we expect a positive value for φ_1 in this test, if the convenience yield is a predictor for future supply risk.[13] For the 3-month regression, we obtain positive and highly significant values for all commodities. In the case of a 15-month time lag, the test yields positive values for all commodities except nickel. The only significant slope coefficients are those of aluminum and copper. For the 27-month regression, only copper yields a positive and significant value.

A comparison of the results of our robustness check with the above regression test confirms the positive relationships for 3M contracts. All slope coefficients are positive and significant with the exception of aluminum. The regression also coincides with our results for 15M aluminum and copper as well as 27M copper. Therefore, the robustness check of our regression model supports the acceptance of H2 for 3M and 27M (and partly for 15M) maturities.

[12]Higher production costs of a specific commodity are usually an indicator of increased supply risk as easy-to-exploit reserves are already exhausted. This effect is not lost by calculating relative prices, as it also makes production more expensive compared to other commodities. The only effects eliminated by the relative price calculation are those such as higher wages for mining workers in general, as they influence production costs for all commodities.

[13] Due to autocorrelation in the residuals, the *t*-values are calculated with Newey-West robust standard errors with the number of lags equal to the fourth root of the sample size.

Table 9: Alternative regression of relative prices at maturity on convenience yields 3, 15, and 27 months (M) prior. Values for the regression coefficients φ_1, φ_2, and explanatory power R^2 (values in brackets are the t-values calculated with Newey-West robust standard errors due to autocorrelation in the residuals in all regressions; ***significance at the 0.1% level; **significance at the 1% level; * significance at the 5% level)

	3M			**15M**			**27M**		
	γ_1	γ_2	R^2	γ_1	γ_2	R^2	γ_1	γ_2	R^2
Aluminum	0.111***	4.961***	0.110	0.050**	4.718***	0.021	–0.036	4.936***	0.007
	(5.840)	(56.705)		(2.402)	(37.126)		(–1.394)	(25.474)	
Copper	0.086***	8.385***	0.341	0.088***	8.341***	0.365	0.022**	8.884***	0.018
	(14.011)	(165.717)		(10.142)	(164.120)		(2.653)	(107.884)	
Lead	0.013***	2.479***	0.067	0.002	2.562***	0.001	–	–	–
	(7.108)	(102.156)		(0.753)	(97.714)				
Nickel	0.473***	32.277***	0.248	–0.050	36.268***	0.002	–0.114	37.108***	0.008
	(8.853)	(68.242)		(–0.982)	(43.728)		(–1.600)	(38.385)	
Zinc	0.082***	3.812***	0.172	0.011	3.705***	0.005	–0.043***	3.915***	0.086
	(9.067)	(81.103)		(1.347)	(67.338)		(–6.418)	(49.028)	

6 Discussion of Results

6.1 Predictive Power of the Convenience Yield

On the basis of our statistical analysis, we can state that the higher the convenience yield of a commodity futures contract, the lower will be the static lifetime of the commodity until the maturity of the contract. We test this with the average static lifetime during the contract period and the lifetime at maturity. The results of our hypothesis tests support Weymar's (1966) theory and empirical validation, which states that convenience yields are related to not only the present but also future inventory levels. As inventory levels show strong autocorrelation, we show a similar relationship by using the static lifetimes of stocks. As those are in general stationary and not autocorrelated, the results appear to be of higher explanatory value, because we use a proxy that is widely detrended for long-term effects, for example, from an increase of consumption over time. The convenience yield can therefore be seen as an indicator of future supply risk for a commodity. Our results are also consistent with the existing literature – we find an inverse relationship between convenience yields and future static lifetime, as stated by Brennan (1958) and Fama and French (1988) in the conventional theory of storage.

That the yield is also an indicator of future price levels is consistent with the relationship between convenience yield and future static lifetime. Static lifetime is defined as the inventory level divided by the turnover. Hence, during time periods of a low static lifetime, we have either low inventories or a high turnover, both of which can increase price levels. This relationship is proved by our results for 3 and 15 months, as well as for 27M copper contracts. In addition, Fama and French (1987) found that prices increase in the future when convenience yields are high. They analyzed the price development for copper, gold, platinum, and silver, and found a positive relationship for several maturities, even though their results are not significant. For longer maturities, it is likely that markets adapt to an increased demand, and so dampen the price increase, as is particularly the case in copper and nickel markets (see below). Furthermore, the liquidity of futures contracts is lower for longer maturities, which might imply less reliable prices and hence distort our analysis to a certain degree. The predictive power of convenience yields on future spot prices might imply inefficiencies in the market, because no price predictions should be possible in efficient markets. Whether a trading strategy leading to significant profits can be found remains questionable.

The analysis reveals two minor weaknesses: First, the results for lead are not reliable in predicting static lifetime. This is not surprising considering that the average amount of lead stocks in LME warehouses during our observation period relative to one year's world production was about two orders of magnitude lower than the corresponding value for the other four metals. Therefore, lead stocks at the LME are not a good proxy for the world stocks of lead. In contrast, 2–3% of the annual production of other metals is stocked at the LME (Commodity Research Bureau, 2008). Comparing this with the price level prediction results, we find that the results for lead are much better in this case, because worldwide prices should not be too different as a result of arbitrage. The LME lead price used in this study can therefore be assumed to be a reasonable proxy for the world price level of lead. Hence, the convenience yield can still be taken as an indicator of future supply risk, and we expect to gain improved results for an appropriate proxy of world inventory levels.

Second, the results of aluminum are less strong than those of other metals. This is particularly true for the 27M contract, in which we find no significant results for the static lifetime at maturity or for prices. However, for the predictive power of average static lifetime until maturity, we find significant results even though their explanatory power is slightly weaker than in other cases. These effects can be explained by the fact that a relaxed supply situation is observed during the period of our analysis (see below). Hence, low static lifetimes might not be a suitable indicator of a critical supply situation for aluminum during this period as the overall supply situation is relatively safe.

6.2 Convenience Yield as Indicator of Supply Risk

Based on the above results, we analyze the ability of the convenience yield to predict the future supply risk of a commodity. As an example, we choose the average static lifetime as a reference indicator because this quantity shows the most robust dependency (see above). We apply an in-sample test to our data and interpret the results with further market information from the U.S. Geological Survey (U.S. Geological Survey, 2011). As a critical supply situation of a commodity, we define a certain value of the average static lifetime of inventory until maturity. As critical, we choose the 20th percentile of the distribution function of static lifetimes. Based on this value, we calculate the corresponding critical convenience yield from the linear model in equation (3) for the average static lifetimes. Based on these two thresholds, we separate our data into four subgroups. We find critical lifetimes that have been correctly predicted and not predicted (alpha error) by a high convenience yield. We also find uncritical lifetimes that have been correctly and incorrectly (beta error) predicted by a low convenience yield.

Table 10: Results for the alpha and beta errors of the convenience yield's predictive power on future supply risk

	alpha error			**beta error**		
	3M	**15M**	**27M**	**3M**	**15M**	**27M**
Aluminum	95%	99%	100%	64%	86%	100%
Copper	46%	47%	68%	8%	28%	38%
Nickel	53%	38%	100%	13%	58%	100%
Zinc	79%	63%	65%	47%	1%	0%

Table 10 lists the results for the alpha and beta errors of the convenience yield's predictive power on future supply risk.[14] In general, we find quite high alpha errors (critical supply situation that is not predicted). Only for 3M and 15M copper and 15M nickel is the error below 50%, although still high.

The beta error (incorrectly predicted critical supply situations) results are better. In the case of copper, we find quite reliable predictive power in the sense that a convenience yield value above the critical level actually predicts a critical supply situation. In particular, beta errors are below 30% for 3M and 15M copper. This implies that the supply situation in the short run is less flexible than in the long run. Actually, we find a continuous supply deficit drawing LME inventory levels down to their minimum at the beginning of 2005. At the same time, world mine production grew continuously, adapting to the excess demand in the long term. Nickel shows some parallels with copper. We find extremely low inventory levels until 2006, followed by a sharp rise. At the same time, we find continuously growing mine production adapting to long-term demand. This is reflected in the good performance of the indicator in terms of beta errors for 3 months and its decreasing performance for longer maturities. Zinc is

[14]The results for lead are not mentioned in Table 10 because the test, with the available data for equation (3), leads to results that are economically not plausible.

the only commodity for which the beta error decreases with longer maturities. This appears to be surprising at first considering that more new information will emerge for longer maturities, and producers and consumers should be able to adapt to potentially critical situations. Instead, we find strikingly low errors between 1% and 0% for 15M and 27M maturities. The results imply that the supply situation is more flexible in the short term due to, for example, sufficient strategic inventories (such as with consumers). However, since production capacity is already at its maximum in the long run, no excess capacity can mitigate an increase in demand. In the middle of the past decade, several mines were closed because of extremely low prices and well-filled stocks. In reaction to this, inventory levels dropped sharply, followed by a sharp peak of the convenience yield in the autumn of 2006. The poor indicator performance for aluminum is not surprising considering that our analysis yielded weaker results for aluminum than for other metals. In general, inventory levels during the past decade show no sharp falls, as in the case of zinc or copper, but there is a rapid increase in 2008. Continuous growth in mine production (except in 2008) and no large fluctuations in absolute inventory levels indicate that aluminum supply, in general, does not undergo major critical situations in the observation period. This is reflected in an extremely small number of critical situations (as predicted) compared to other metals.

In terms of the supply risk of the four metals, we find that the situation for aluminum is quite relaxed in the observation period. Copper and nickel show critical supply situations due to rapidly growing demand, which is matched only delayed by the production. Zinc appears to undergo the most critical path as the long-run supply is not safe enough because of production capacity cuts. This is in line with the EU report on critical raw materials (European Commission, 2010), which finds the lowest availability risk for aluminum, followed by copper and nickel at about the same level, and the highest for zinc.

Technically, we can conclude that the performance of the convenience yield as an indicator of supply risk reasonably reflects fundamental facts. For commodities with low inventory levels during the observation period, we find that a high convenience yield predicts a critical supply in the short run. For commodities with continuous excess demand and shrinking production capacity, the long-run indicators perform well.

7 Conclusion and Outlook

According to the classical theory of storage, the convenience yield of commodity futures depends on the inventory level of the commodity, and is high if inventory levels are low, and vice versa. As stated by Weymar (1966), the convenience yield also depends on the future inventory level of a commodity, which is important to producers. In our empirical analysis, we therefore examine the forecasting power of convenience yields for the future supply risk of a commodity. We test the predictive power of the convenience yield of commodity futures on the static lifetime of inventory (which is the inventory level divided by turnover) as well as on the future spot price at the maturity of the contract. These two variables are regarded as indicators of the current supply risk of a commodity. To test the relationships, we use trading data on 3M, 15M, and 27M maturities of five major industrial metals (aluminum, copper, lead, nickel, and zinc) for the period 1999 until 2011, obtained from the London Metal Exchange. The statistical analysis yields very robust results for both average static lifetime of stocks until maturity and lifetime at maturity. A limitation of the indicator is that it works only as long as the inventory level is a good proxy for worldwide stocks and the supply situation bears at least a small risk of disruption. We find an inverse dependency of static lifetime at maturity on foregone convenience yields. For the prediction of future spot prices, we also find robust results. High convenience yields are followed by higher prices at maturity.

This might indicate that complete market efficiency does not exist in the futures market, although it remains unclear if profits can be generated based on this finding. Nevertheless, we show that, with some limitations, the convenience yield serves as an appropriate predictor of a commodity's future supply risk.

An implication of our results is that further research should focus on constructing an indicator based on convenience yields and, at the same time, address the limitations mentioned above. Furthermore, the validity of the results should be broadened by analyzing more commodities and conducting further empirical analysis that addresses the autoregressive properties of the relationships. A further aspect to be addressed in the future is the relevance of our results to market efficiency.

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