Convenience Yield Risk Premiums [1]

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Convenience Yield Risk Premiums

Abstract

The convenience yield is an important risk factor for commodity derivatives. However, very little is known about how convenience yield risk is priced. In this paper, we construct portfolios of commodity futures that directly track the convenience yield risk premium. Our empirical results for a variety of different commodities show that convenience yield risk premiums are consistently positive. However, the magnitude of the premium varies strongly between groups of commodities. Our study has important implications for the risk management of commodity positions and shows that convenience yield risk premiums can be very valuable for investors. For grains, a risk-averse investor realizes monetary utility gains over a risk-free investment of up to 11% per year from a corresponding trading strategy.

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1 Introduction

Commodity futures have long been used by producers and consumers to manage commodity price risk. More recently, they have also received much attention in the context of commodity investment strategies and the growth in commodity investments via futures trading has even led to a controversial debate about the financialization of commodity markets.[1] Given the importance of commodity futures, a good understanding of the factors behind their risk and return is a crucial issue for producers, consumers and commodity investors alike.

The convenience yield, i.e., the "flow of services which accrues to the owner of a physical inventory but not to the owner of a contract for future delivery",[2] is an important determinant of commodity futures prices. The literature on convenience yields shows that they can vary strongly over time and should be treated as stochastic.[3] However, it is astonishing that previous research provides rather limited evidence on convenience yield risk premiums. A better understanding of the risk premiums is important for different reasons. First, the premiums affect firms' risk management and hedging strategies with futures contracts because they are a component of the costs and benefits of hedging. Second, commodity investment strategies with futures require a thorough assessment of the risk-return trade-off and should also consider convenience yield risk premiums. Finally, a better understanding of the premiums could improve pricing models for commodity derivatives via a more adequate specification of

[1]See, for example, Stoll and Whaley (2010), Irwin and Sanders (2011), Tang and Xiong (2012), and Basak and Pavlova (2013)

[2]See Brennan (1991), p.33.

[3]Even is one does not follow the economic notion of a convenience yield, there is no doubt that a second stochastic factor besides the commodity spot price is required to explain commodity futures prices. For example, Schwartz and Smith (2000) develop a two-factor model with stochastic long-term and short-term spot price components. They show that this model is observationally equivalent to the stochastic convenience yield model by Gibson and Schwartz (1990).

the market price of convenience yield risk.

In this paper, we investigate the convenience yield risk premium for different commodities and make the following two contributions. First, we shows how to extract the premium by means of a trading strategy with commodity futures. This trading strategy is easy to implement because it is based on the knowledge of current futures prices alone. The returns of this strategy are natural estimates of the premium. Second, we perform an extensive empirical study that quantifies the convenience yield risk premium for different commodities and assesses the value of the corresponding trading strategy for investors.

Our empirical results for a variety of different commodities show that convenience yield risk premiums are consistently positive. However, the magnitude of the premium varies strongly between groups of commodities. These results are very robust and do not depend on the sub-period investigated, the specific contracts used and the consideration of additional interest rate risk. Convenience yield risk premiums can be very valuable for investors. For grains, a risk-averse investor realizes monetary utility gains over a risk-free investment of up to 11% per year from a corresponding trading strategy.

Our work is related to different strands of the literature. There is a natural link to the literature on the convenience yield itself. Starting with the classical contributions by Kaldor (1939) and Working (1949), this literature studies the economic rationale behind the convenience yield, its determinants and empirical properties (See, for example, Brennan (1991), Casassus et al. (2005), Bollinger and Kind (2010), and Prokopczuk and Wu (2013)). However, this literature deals with the convenience yield itself and does not investigate the convenience yield risk premium that we study in our paper.

Some evidence on convenience yield risk premiums is provided by studies that develop and test pricing models for commodity derivatives, because such models often require the estimation of the market price of convenience yield risk (see Gibson and Schwartz (1990), Schwartz (1997), Casassus and Collin-Dufresne (2005), and Casassus et al. (2012)). However, such estimates are notoriously imprecise and have to be obtained simultaneously with all other model parameters. In contrast, we follow a more direct approach that exploits the returns of a trading strategy. Our approach is also model based but does not require any knowledge of unknown model parameters.

In terms of methodology, our work is related to some studies of the variance risk premium (see Coval and Shumway (2001), Bakshi and Kapadia (2003), and Carr and Wu (2009)). These papers analyze the similar problem of extracting the risk premium of a stochastic factor (stochastic volatility) that affects derivatives prices (options) and interacts with another factor (spot price). To obtain the premium, these studies also use certain trading strategies. However, we deal with the convenience yield risk premium instead of the variance risk premium. The former is more relevant for commodity futures whereas the latter is more relevant for options.

Finally, our work belongs to the extensive literature on trading strategies and risk premiums in commodity futures markets. (See Basu and Miffre (2009) Bessembinder (1992), Bessembinder and Chan (1992), Chang (1985), Chng (2009), Dusak (1973), Erb and Harvey (2006), Fama and French (1987), Gorton and Rouwenhorst (2006), Miffre and Rallis (2007), de Roon et al. (2000), de Roon et al. (1998), Rouwenhorst and Tang (2012), and Szakmary et al. (2010). Most closely related to our work are the papers by Daskalaki et al. (2012) and Szymanowska et al. (2013). These authors investigate the structure of risk premiums in futures markets and relate it to different risk factors. However, our paper is the first one that explicitly considers the convenience yield risk premium and investigates a futures trading strategy derived to track this premium.

The remainder of the paper is organized as follows. In Section 2 we show how to extract the convenience yield risk premium via a trading strategy with commodity futures. Section 3 provides our empirical study. After introducing our data in Subsection 3.1, we present our results on the sign and magnitude of the risk premiums in Subsection 3.2. Subsection 3.3 deals with the benefits of our futures trading strategy for investors. Section 4 concludes.

2 Extracting Convenience Yield Risk Premiums

To extract convenience yield risk premiums, we study the returns of futures portfolios that are sensitive to convenience yield changes. We insulate the portfolios from spot price risk by choosing appropriate positions in contracts with different maturities. The portfolio construction is based on the two-factor pricing model by Gibson and Schwartz (1990). This model considers a stochastic commodity spot price and a stochastic convenience yield rate. The two state variables follow the stochastic processes

$$d\,S(t) = (\mu(S,t) - \delta)S \cdot dt + \sigma_1 S \cdot dw_1 \ , \tag{1}$$

$$d\,\delta(t) = a\,(b - \delta) \cdot dt + \sigma_2 \cdot dw_2 \ , \tag{2}$$

where S is the spot price and δ the convenience yield rate. $\mu(S,t)$ denotes a drift component of the spot price process that can depend on S and time t.[4] The convenience yield rate is mean reverting with stationary mean b and mean-reversion parameter a. σ_1 and σ_2 are volatility

[4]As the drift rate can be a function of time, the model allows for seasonality of the spot price process.

parameters and dw_1 and dw_2 denote the increments of two correlated Brownian motions with correlation parameter ρ_{12}. The model delivers the following closed-form solution for the futures price:

$$F(t,\tau) = S(t)\, exp\Big[-\delta(t)\frac{(1-e^{-a\,\tau})}{a} + A(\tau)\Big]\,, \text{ with} \tag{3}$$

$$\begin{aligned} A(\tau) \quad &= \quad \Big[r - (b - \frac{\sigma_2\,\gamma}{a}) + \frac{1}{2}\frac{\sigma_2^2}{a^2} - \frac{\sigma_1\sigma_2\,\rho_{12}}{a}\Big]\,\tau + \sigma_2^2\frac{(1-e^{-2a\,\tau})}{4\,a^3} \\ &\quad + \Big[a\,(b - \frac{\sigma_2\,\gamma}{a}) + \sigma_1\sigma_2\,\rho_{12} - \frac{\sigma_2^2}{a}\Big]\frac{(1-e^{-a\,\tau})}{a^2}, \end{aligned}$$

where t is calender time, τ the future's time-to-maturity, r the risk-free interest rate, and γ the market price of convenience yield risk.

It is our goal to build portfolios that bear some convenience yield risk but are insensitive to spot price changes, i.e., delta-neutral portfolios. From the pricing equation (3), we easily obtain the spot price sensitivity of a futures contract:

$$\frac{\partial F(t,\tau)}{\partial S(t)} = \frac{F(t,\tau)}{S(t)}. \tag{4}$$

According to equation (4), a future's delta equals the current futures price divided by the current spot price. This property is very convenient, because delta can be obtained directly from observable prices and does not require any (potentially imprecise) estimates of model parameters.

Now consider a portfolio that consists of positions in two different futures contracts with times to maturity τ_1 and τ_2, where $\tau_1 < \tau_2$. Denote the number of long positions in the first futures by x_1 and the number of long positions in the second one by x_2. Then the futures portfolio has a delta of $[x_1 F(t,\tau_1) + x_2 F(t,\tau_2)]/S(t)$. Therefore, delta-neutrality of the portfolio requires

$$\frac{x_1}{x_2} = -\frac{F(t,\tau_2)}{F(t,\tau_1)}. \tag{5}$$

In our analysis, we choose the following values for x_1 and x_2:

$$x_1 = \frac{1}{F(t,\tau_1)} \quad \text{and} \quad x_2 = -\frac{1}{F(t,\tau_2)}. \tag{6}$$

This choice facilitates the comparison between different commodities with different price levels, because profits or losses of the futures positions can be interpreted as price changes per dollar, i.e., relative changes of futures prices. Also note that we don't need any of the model parameters to obtain x_1 and x_2. In the setting of the Gibson and Schwartz (1990) model, the resulting portfolio is (instantaneously) free of spot price risk – only convenience yield risk remains. In addition, it does not require any initial investment. Therefore, the portfolio's expected profit is a pure compensation for convenience yield risk, i.e., it is a convenience yield risk premium.

For a better understanding of the portfolio's properties, let us look at the (instantaneous) change in portfolio value. From Itô's lemma, we obtain

$$\frac{dF(t,\tau_1)}{F(t,\tau_1)} - \frac{dF(t,\tau_2)}{F(t,\tau_2)} = \gamma\,\frac{\left(e^{-a\tau_1} - e^{-a\tau_2}\right)\sigma_2}{a} + \frac{\left(e^{-a\tau_1} - e^{-a\tau_2}\right)\sigma_2}{a}\,dw_2. \tag{7}$$

Equation (7) confirms that portfolio risk is driven by the innovation dw_2 of the convenience yield process only. Spot price risk (dw_1) does not appear. The portfolio's profit or loss could nevertheless be correlated with changes in the spot price, because of a correlation between the innovations dw_1 and dw_2. Another interesting observation is that the distribution of the portfolio's instantaneous profit does not depend on the state variables, i.e., it is not affected by the current commodity price and the current convenience yield.

The volatility of the portfolio's profit equals $\frac{(e^{-a\tau_1}-e^{-a\tau_2})\sigma_2}{a}$. It increases with a higher convenience yield volatility (σ_2) and decreases with a higher mean-reversion (a) of the convenience yield process. Moreover, the times-to-maturity of the two futures contracts play an important role. The volatility increases with τ_2 and decreases with τ_1, which means that a growing distance between the maturity dates of the two futures leads to a higher volatility. The portfolio's expected profit equals the market price of convenience yield risk times the portfolio's volatility. Therefore, the expected profit is positive for $\gamma > 0$ and negative for $\gamma < 0$. Equation (7) also highlights that γ provides the risk compensation per unit of risk, as it equals the ratio of the expected portfolio profit and the portfolio volatility. In summary, we can conclude that the portfolio's profits and losses provide useful information on convenience yield risk premiums that we will exploit in our empirical study.

3 Empirical Study

3.1 Data

In our empirical analysis, for the investigation of convenience yield risk premiums, we consider data on futures contracts for eight major commodity markets. In particular we examine the following commodities that can be clustered in three groups, namely *metals* (gold, silver and copper), *grains* (corn, soybeans and wheat) and *energy* (oil and gas). For these commodities data on futures prices is supplied by CME Group[5]. The corresponding futures contracts have high trading volume, high liquidity and can been seen as benchmark contracts for the particular commodity. Unfortunately, we can not retrieve data for the entire sample period from 1975 to 2010 for all commodities such that our sample period differs for some of the commodities depending on when data on futures prices is available in the futures exchange. Sample periods are from January 1, 1975 to October 1, 2010 for gold, silver, corn, soybean and wheat, as well as August 1, 1988 to October 1, 2010 for copper, July 1, 1986 to October 1, 2010 for crude oil and April 1, 1990 to October 1, 2010 for natural gas. Spot and futures prices are quoted in US Dollar (USD) cents per unit of each commodity quantity: USD cents per pound for copper, USD cents per troy ounce for gold and silver, USD cents per bushel for grains (corn, soybean and wheat), USD cents per barrels for crude oil and USD cents per million British thermal units (mmBtu) for natural gas.

We consider both monthly spot and futures prices for all commodities. Note, however, that the 'spot' here refers to the corresponding futures contract that is closest to maturity, as in Schwartz (1997). We use this proxy because for several of the considered commodity markets, spot price data is not very reliable, see e.g. Gibson and Schwartz (1990). Table 1 provides sample periods as well as descriptive statistics for monthly returns for the nearest-term futures contracts for the eight commodities considered in this analysis.

[5] http://www.cmegroup.com/

Table 1: Sample periods and descriptive statistics of monthly spot returns for the considered commodities. We examine eight commodities hat can be clustered in three groups, namely *metals* (gold, silver and copper), *grains* (corn, soybeans and wheat) and *energy* (oil and gas). Note that the term *spot* here refers to the corresponding futures contract that is closest to maturity, as in Schwartz (1997).

	Metals			Grains			Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	0.50%	0.41%	0.33%	0.14%	0.19%	0.15%	0.69%	0.98%
σ	5.50%	9.38%	8.17%	7.64%	7.46%	8.23%	10.95%	18.24%
Min	-23.10%	-75.33%	-53.54%	-28.75%	-55.19%	-55.19%	-53.40%	-63.07%
Max	24.12%	44.81%	31.22%	40.67%	25.37%	33.19%	37.07%	56.49%
Start	Jan 75	Jan 75	Aug 88	Jan 75	Jan 75	Jan 75	Jul 86	Apr 90
End	Oct 10	Oct 10	Oct 10	Oct 10	Oct 10	Oct 10	Oct 10	Oct 10
Obs	427	427	259	431	431	431	288	224

3.2 Estimates of Risk Premiums

3.2.1 Base Case

In a first step we examine estimates for convenience yield risk premiums, by studying the returns of the constructed futures portfolios. Recall that the portfolio construction is based on the two-factor pricing model by Gibson and Schwartz (1990) and the created portfolios are insulated from spot price risk by choosing appropriate positions in contracts with different maturities. Table 2 provides results for annualized returns for the created portfolios, i.e. for estimated convenience yield risk premiums for the considered time period from January 1, 1975 to October 1, 2010 for gold, silver, corn, soybean and wheat, as well as for August 1, 1988 to October 1, 2010 for copper, July 1, 1986 to October 1, 2010 for crude oil and for April 1, 1990 to October 1, 2010 for natural gas.

As mentioned above, we divide the portfolios into different groups of commodities, namely *metals*, *grains* and *energy*. Observed returns for the created factor portfolios show that similar

Table 2: Estimates for convenience yield risk premiums based on monthly returns obtained from the constructed futures portfolios for different groups of commodities: *metals* (gold, silver and copper), *grains* (corn, soybeans and wheat) and *energy* (oil and gas). Portfolio construction is based on the two-factor pricing model by Gibson and Schwartz (1990) and the portfolios are insulated from spot price risk by choosing appropriate positions in contracts with different maturities. We report annualized figures for average returns, standard deviations, and Sharpe ratios. Note also the different number of observations for the considered commodities based on the different underlying samples.

	Metals			Grains			Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	4.96%	4.49%	4.82%	11.92%	10.53%	11.24%	1.19%	7.26%
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.535)	(0.172)
σ	1.13%	4.52%	4.19%	6.81%	8.87%	13.64%	9.24%	21.04%
SR	377.65%	99.43%	115.14%	175.17%	118.68%	82.44%	12.83%	34.53%
Obs	429	429	261	108	215	108	291	246

commodities yield very similar returns. For gold, silver and copper, annualized returns range from 4.49% for silver to 4.96% for gold that are significantly positive. For grains we find that annualized returns are in a range from 10.53% for soybeans up to 11.92% for corn, while for wheat annualized returns are 11.24%. Finally, for oil we obtain an estimate of the convenience yield risk premium of 1.19%, while for gas we obtain annualized portfolio returns of 7.26%.

It becomes obvious that our estimates for the convenience yield risk premiums are positive for all commodities. However, given the relatively high standard deviation of monthly returns for oil and gas, the convenience yield risk premium is only significant for the groups of metals and grains.[6] Also calculated annualized Sharpe ratios illustrate that values are high for metals and grains, while they are significantly lower for energy commodities. For metals we find Sharpe ratios between 99.43% for silver up to 377.65% for gold, while for grains the

[6] We use robust Newey-West standard errors with 12 lags to asses the significance of the average returns.

equivalent figures range from 82.44% for wheat up to 175.17% for corn.

Overall, our results suggest that the estimated convenience yield risk premiums are positive for all commodities, while they are quite substantial and significant in particular for metals and grains. We conclude that with respect to the futures portfolios, there exist clear differences between the examined groups of commodities: returns for grain portfolios are the highest, while for metals we obtain lower annualized returns but also a much lower standard deviation in the returns such that estimated convenience yield risk premiums are still positively greater than zero. On the other hand for energy commodities, we do not find a significant convenience yield risk premium.

3.2.2 Influence of Sub-periods

In a next step we examine whether our results on convenience risk premiums still remain valid when considering different sub-periods. Table 3 reports results for three sub-periods, ranging from January 2000 - October 2010 (*Panel A*, from January 1990 - December 1999 (*Panel B* and from January 1980 - December 1989 (*Panel C*. From a first glance we find that for all constructed portfolios, with the exceptions of oil for the sub-period January 1990 - December 1999, estimated convenience yield risk premiums remain positive.

For metals, we find that returns for constructed gold and silver futures portfolios were particularly high during the first sub-period January 1980 - December 1989: for this period, estimates of the convenience yield risk premium are 8.65% for gold and 4.73% for silver. Note that for this sub-period, we do not report the results for copper, since data was only available from August 1988 onwards. Results for the second sub-period from January 1990 - December 1999 are all significantly greater than zero at the 1% significance level and annualized premiums range from 3.43% for gold up to 4.64% for copper. Finally, also for the third sub-period from January 2000 - October 2010 we obtain slightly lower but still significant positive annualized returns for gold (2.65%) and silver (2.45%), while returns for copper are 5.53%. We conclude that for metals our results on positive convenience yield risk premiums are robust also across the considered sub-periods.

Also for grains, we find that estimated convenience yield risk premiums are positive throughout all sub-periods for all commodities. For the first sub-period January 1980 - December 1989 annualized returns are 17.81% for corn, 14.53% for soybeans and 9.25% for wheat. For corn and soybeans, estimated convenience yield risk premiums are significantly greater than zero at the 1.5% and 0.1% level, respectively, while returns for are still comparably high but not significant for the first sub-period. For the second sub-period annualized returns for the created grain futures portfolios are all significant at the 5% level and range from 12.06% for soybeans up to 23.72% for wheat. Also for the third sub-period from January 2000 - October 2010 we obtain slightly lower but highly significant positive estimates for convenience yield risk premiums for corn (7.58%), soybeans (11.02%) and wheat (7.65%). Overall, we find that also for grains our results on positive and significant returns of the constructed factor portfolios are robust.

Let us now consider the results for the third group of energy commodities. For the first sub-period from January 1980 - December 1989, we only report results for oil, since futures prices for natural gas were only available from April 1990 onwards. Estimated convenience yield risk premiums for oil are positive (5.88%), but due to a high standard deviation of the created monthly portfolio returns they are not significant, at least not at the 5% level. For the second sub-period from January 1990 - December 1999, annualized returns for the

Table 3: Estimates of convenience yield risk premiums for *metals* (gold, silver and copper), *grains* (corn, soybeans and wheat), *energy* (oil and gas) for different sub-periods. Data is divided into three sub-periods, ranging from January 2000 - October 2010 (*Panel A*), from January 1990 - December 1999 (*Panel B*) and from January 1980 - December 1989 (*Panel C*). We report annualized figures for average returns, standard deviations, and the Sharpe ratios. Note also the different number of observations for the considered commodities based on the different underlying samples for the sub-periods.

				Panel A: Jan 2000 - Oct 2010				
		Metals			Grains		Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	2.65%	2.45%	5.53%	7.58%	11.02%	7.65%	2.08%	5.47%
	(0.000)	(0.000)	(0.023)	(0.000)	(0.001)	(0.000)	(0.220)	(0.214)
σ	0.50%	0.54%	3.37%	4.47%	11.70%	4.74%	8.68%	18.17%
SR	532.37%	457.55%	164.03%	169.81%	94.18%	161.47%	23.93%	30.08%
Obs	130	130	130	33	66	33	130	130
				Panel B: Jan 1990 - Dec 1999				
		Metals			Grains		Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	3.43%	4.25%	4.64%	12.63%	12.06%	23.72%	-0.70%	9.28%
	(0.000)	(0.000)	(0.009)	(0.0412)	(0.000)	(0.005)	(0.857)	(0.353)
σ	0.45%	0.65%	4.84%	7.40%	6.64%	19.54%	8.53%	23.91%
SR	765.30%	650.63%	96.58%	170.53%	181.45%	121.39%	-8.18%	38.81%
Obs	120	120	120	30	30	30	120	116
				Panel C: Jan 1980 - Dec 1989				
		Metals			Grains		Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	8.65%	4.73%	–	17.81%	14.53%	9.25%	5.88%	–
	(0.000)	(0.112)	–	(0.015)	(0.001)	(0.120)	(0.095)	–
σ	1.69%	8.20%	–	8.73%	7.85%	15.03%	12.52%	–
SR	510.14%	57.64%	–	204.01%	185.10%	61.58%	46.95%	–
Obs	120	120	–	30	60	30	41	–

created energy futures portfolios are negative for oil (-0.70%), while they are positive and relatively high for gas (9.28%). However, neither for oil nor gas the estimated risk premiums are significant. For the third sub-period we obtain positive estimates for convenience yield risk premiums for oil (2.08%) and gas (5.47%) but similar to the other sub-periods due to a high standard deviation of the created monthly portfolio returns the premiums are not significant. So also for energy futures contracts our results for different sub-periods tend to confirm the findings obtained for the entire period.

Overall, results on the sign and significance of convenience yield risk premiums are robust for the considered sub-periods. We obtain positive and significant returns for the constructed futures portfolios for metals and grains, while returns from created energy portfolios are predominantly positive but not significant. So we confirm results on the existence of a positive convenience yield risk premium for metals and grains while for energy commodities, we do not find significant convenience yield risk premiums.

3.2.3 Influence of Maturity Choice

In a next step we examine the robustness of the estimated convenience yield risk premiums with respect to the choice of futures contracts. Recall that for our base case analysis, for metals and energy commodities, the factor portfolios are constructed by taking a long position in one-month futures contracts and a short position in two-month futures contacts, while the weights for each position were chosen according to equation (6). For grains, the constructed portfolios are based on a long position in the one-month futures contract and a short position in the three-month futures contacts. In the following, we analyze whether our results on estimated convenience yield risk premiums are robust also with respect to the contract choice, i.e. we examine whether the maturity of the contracts being used to create the portfolios has an impact on the convenience yield risk premium. To do this, we construct our portfolios now by also using futures contracts with longer maturities. Table 4 provides results on estimated convenience yield risk premiums when portfolios are created by taking a long position with

Table 4: Estimates of convenience yield risk premiums for *metals* (gold, silver and copper), *grains* (corn, soybeans and wheat), *energy* (oil and gas) for alternative contract choice. Portfolios are constructed by taking a long position with weight $x_1 = \frac{1}{F(t,\tau_1)}$ in the nearest term futures contracts, and a short position with weight $x_2 = \frac{1}{F(t,\tau_2)}$ in the third nearest term futures contract.

	Metals			Grains			Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	5.42%	4.98%	4.00%	12.58%	10.49%	13.01%	1.12%	1.80%
	(0.000)	(0.000)	(0.013)	(0.000)	(0.000)	(0.063)	(0.681)	(0.814)
σ	1.37%	5.09%	5.65%	6.99%	9.77%	18.31%	11.91%	28.93%
SR	394.10%	97.81%	70.84%	180.03%	107.31%	71.05%	9.38%	6.21%
Obs	215	214	258	72	215	72	291	246

weight $x_1 = \frac{1}{F(t,\tau_1)}$ in the nearest term futures contracts, and a short position with weight $x_2 = \frac{1}{F(t,\tau_2)}$ in the third nearest term futures contract. For metals and energy this refers to a long position in the one-month futures and a short position in the three-month futures contract, while for grains we use a long position in the one-monh futures contract and a short position in the five-month futures contract. Note that returns for the constructed portfolios are still calculated on a monthly basis, i.e. each month existing positions in the futures contracts are being closed out and new factor portfolios are constructed.

We find that our results on the sign and significance of estimated convenience yield risk premiums as presented in Table 4 are robust also with respect to the choice of contracts. This means that also for futures contracts with longer maturities we obtain significant positive convenience yield risk premiums for metals and grains, while the premiums are positive but insignificant for energy commodities. We find that also the magnitude of the premiums is similar to the base case: annualized returns for the constructed portfolios range from 4.00% for copper to 5.42% for gold and are all significant, even at the 1% level. As for the base case, for grains we find that annualized returns are higher with 12.58% for corn, 10.49% for soybeans and 13.01% for wheat. For corn and soybeans we find estimated convenience yield risk premiums to be significant at any reasonable level, while for wheat they are only significant at the 10% level. Finally, for energy commodities, annualized returns for the constructed futures portfolios are rather low (1.12% for oil and 1.80% for gas) and not significant. Note that we also considered other combinations of futures contracts with even longer maturities and obtained similar results with respect to the sign and significance of estimated convenience yield risk premiums. These results are not reported here, but are available upon request to the authors.

Overall, we conclude that also when alternative futures contracts with longer maturities are used to create the factor portfolios, our results on convenience yield risk premiums for different groups of commodities still remain valid.

3.2.4 Influence of Interest Rate Risk

The portfolio strategy we have studied so far was derived from the Gibson and Schwartz (1990) model, which assumes constant interest rates. The question that we investigate now is whether interest rate risk affects our conclusions about convenience yield risk premiums. Schwartz (1997) develops a three-factor extension of Gibson's and Schwartz's model with stochastic interest rates. The stochastic processes of the commodity spot price and the convenience yield rate are the same as in equations (1) and (2). In addition, Schwartz (1997) uses a one-factor Vasicek interest rate model that is based on the following dynamics of the short rate:

$$dr(t) = k\,(m - r) \cdot dt + \sigma_3 \cdot dw_3 \ , \tag{8}$$

with mean-reversion parameter k, stationary mean m and volatility σ_3. The model yields the following closed-form solution for the futures price:

$$F(t,\tau) = S(t)\, exp\Big[-\delta(t)\frac{(1-e^{-a\,\tau})}{a} + r(t)\frac{(1-e^{-k\,\tau})}{k} + B(\tau)\Big] \,, \tag{9}$$

where $B(\tau)$ is a function of the time-to-maturity and all model parameters, but does not depend on any of the three state variables.

To study convenience yield risk, we need portfolios that are insensitive to changes in the spot price and the interest rate. From the pricing equation (9), we obtain the following spot price sensitivity (delta) and interest rate sensitivity (rho) of a futures:

$$\frac{\partial F(t,\tau)}{\partial S(t)} = \frac{F(t,\tau)}{S(t)} \quad \text{and} \quad \frac{\partial F(t,\tau)}{\partial r(t)} = F(t,\tau)\frac{1-\exp(-k\tau)}{k}. \tag{10}$$

Now assume that three different futures with times-to-maturity τ_1, τ_2 and τ_3 ($\tau_1 < \tau_2 < \tau_3$) exist and denote the number of contracts held in these futures by x_1, x_2 and x_3, respectively. Then a futures portfolio is delta neutral and rho neutral if x_1, x_2 and x_3 solve the following system of equations:

$$x_1 F(t,\tau_1) + x_2 F(t,\tau_2) + x_3 F(t,\tau_3) = 0 \,, \tag{11}$$

$$x_1 F(t,\tau_1)\exp(-k\tau_1) + x_2 F(t,\tau_2)\exp(-k\tau_2) + x_3 F(t,\tau_3)\exp(-k\tau_3) = 0. \tag{12}$$

As in Section 2, we choose $x_1 = 1/F(t, \tau_1)$. With this choice, the solutions for x_2 and x_3 are

$$x_2 = \frac{1}{F(t,\tau_2)} \left[\frac{\exp(-k\tau_1) - \exp(-k\tau_3)}{\exp(-k\tau_3) - \exp(-k\tau_2)} \right], \tag{13}$$

$$x_3 = \frac{1}{F(t,\tau_3)} \left[\frac{\exp(-k\tau_2) - \exp(-k\tau_1)}{\exp(-k\tau_3) - \exp(-k\tau_2)} \right]. \tag{14}$$

Because $\tau_1 < \tau_2 < \tau_3$ and $k > 0$, the portfolio consists of a long position in the shortest-term futures, a short-position in the intermediate-term futures and a long position in the longest-term futures. Unfortunately, the appropriate futures positions can no longer be obtained from observable prices only. In addition, we need the mean-reversion parameter k of the short-rate process. However, this parameter is easy to estimate. We apply the Maximum Likelihood approach outlined in Schwartz (1997) and estimate k from zero-bond prices. We use ten different maturities between one and ten years and monthly observations over the investigation period from January 1975 to October 2010. Our data source are the Treasury yield curves provided by the Federal Reserve System.[7] The resulting estimate of k is 0.62. Based on this value, we build futures portfolios according to equations (13) and (14). For crude oil, gas, gold, silver, and copper, we employ futures with times-to-maturity of one, two, and three months. For corn, wheat and soybeans, we use one-, three- and five-months futures. As a robustness check, we consider two alternative futures portfolios based on $k = 0.22$ and $k = 1.02$.

Our results are presented in Table 5. We find that our conclusions on the sign and significance of estimated convenience yield risk premiums generally remain valid when portfolios are

[7] For details on this data set see Gurkaynak et al. (2007).

Table 5: Impact of interest rate risk on estimates for convenience yield risk premiums. Results reported are based on the Schwartz (1997) three-factor extension of the Gibson and Schwartz model with stochastic interest rates. For crude oil, gas, gold, silver, and copper, we employ futures with times-to-maturity of one, two, and three months, for corn, wheat and soybeans, we use one-, three- and five-months futures contracts. The mean-reversion parameter k of the short-rate process is estimated using the Maximum Likelihood approach outlined in Schwartz (1997) and estimates of k are derived from zero-bond prices. Results for the parameter estimate $k = 0.62$ are reported in *Panel A* while for a robustness check, we also consider alternative futures portfolios based on $k = 0.22$ (*Panel B*) and $k = 1.02$ (*Panel C*).

				Panel A: k=0.62				
		Metals			Grains		Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	4.56%	2.98%	5.92%	8.56%	10.57%	18.50%	1.26%	13.02%
	(0.000)	(0.088)	(0.000)	(0.000)	(0.000)	(0.000)	(0.428)	(0.000)
σ	1.71%	6.96%	3.67%	4.94%	8.99%	16.40%	7.51%	16.96%
SR	266.80%	42.89%	161.02%	173.34%	117.54%	112.77%	16.75%	76.77%
Obs	215	214	258	72	215	72	291	246
				Panel B: k=0.22				
		Metals			Grains		Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	4.58%	3.02%	5.88%	8.70%	10.57%	18.31%	1.26%	12.83%
	(0.000)	(0.083)	(0.000)	(0.000)	(0.000)	(0.000)	(0.428)	(0.000)
σ	1.68%	6.91%	3.67%	4.82%	8.95%	16.31%	7.54%	16.99%
SR	271.94%	43.65%	160.44%	180.54%	118.09%	112.28%	16.65%	75.55%
Obs	215	214	258	72	215	72	291	246
				Panel C: k=1.02				
		Metals			Grains		Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
μ	4.55%	2.95%	5.95%	8.42%	10.57%	18.70%	1.26%	13.22%
	(0.000)	(0.094)	(0.000)	(0.000)	(0.000)	(0.000)	(0.428)	(0.000)
σ	1.74%	7.01%	3.68%	5.08%	9.09%	16.52%	7.48%	16.95%
SR	261.60%	42.11%	161.53%	165.64%	116.88%	113.20%	16.85%	78.00%
Obs	215	214	258	72	215	72	291	246

constructed based on a three-factor extension of the Gibson and Schwartz (1990) model. We obtain positive and highly significant convenience yield risk premiums for all metals and grains except for silver. For silver, we find that monthly returns from the created futures portfolio are positive, but usually only significant at the 10% level. On the other hand, we obtain positive but insignificant convenience yield risk premiums for oil. Interestingly, for natural gas futures portfolios based on a three-factor model, estimated convenience yield risk premiums are also comparably large (around 13%) and highly significant. With respect to the magnitude of the calculated risk premiums, we find that for most commodities results are comparable to the two-factor base case. Created annualized returns are around 4.5% for gold, approximately 6% for copper, while they are clearly higher for the considered grains. Interestingly, obtained annualized risk premiums are lower (around 8.5%) for corn, while they are much higher (around 18.5%) for wheat in comparison to the two-factor base case. However, in both cases the results on positive and highly significant convenience yield risk premiums remain valid. Clearly, for silver, obtained returns from the factor portfolio are lower than for the base case (around 3% in comparison to 4.5%), while they are much higher for gas (around 13%) in comparison to 7% for the two-factor model. Thus, for silver and natural gas our results seem to be affected by the inclusion of an additional interest-rate factor when creating portfolios that are insulated from spot price risk but subject to convenience yield risk. We find that the choice of the mean-reversion parameter k does not seem to have a a significant impact on the results. Comparing results for *Panel A* ($k = 0.62$) with *Panel B* ($k = 0.22$) and *Panel C* ($k = 1.02$) we obtain very similar results for the estimated convenience yield risk premiums. This is true not only for the sign, but also for the magnitude and significance of the extracted premiums. For example, annualized returns for the constructed portfolios for gold vary between 4.55% and 4.58% depending on the choice of k, while for wheat estimates for the convenience yield risk premium are between 18.31% and 18.70%. Overall, we conclude that results on the sign and significance of estimated convenience yield risk premiums are robust also with respect to constructing the futures portfolios based on a three-factor extension of the Gibson and Schwartz (1990) model. In particular, we find that results are insensitive to the choice of the mean-reversion parameter k in the Vasicek interest rate model.

3.3 Benefits for Investors

In this section we examine benefits of constructing portfolios that are sensitive to convenience yield changes for investors. In particular we calculate monetary utility gains (MUGs) as in Ang and Bekaert (2002) for the constructed portfolios. We also examine the correlations between monthly returns from the constructed convenience yield sensitive portfolios across the different classes of commodities as well as against monthly spot returns of the considered commodities.

3.3.1 Monetary Utility Gains

In the following we examine the benefits of the constructed futures portfolios for investors. Table 6 reports the annualized monetary utility gains (MUGs) of the created convenience yield sensitive portfolios for each of the commodities. The MUG is the monetary compensation (in excess returns over a risk-free investment) that an investor requires to be willing to switch from the portfolio strategy that invests in our convenience yield sensitive futures portfolio to a benchmark portfolio strategy. In this study, we use a risk-free investment as the benchmark strategy, i.e., a strategy that delivers an excess return of zero with certainty. Of course, MUGs depend on the risk aversion of the investor. In Table 6, we report MUGs for investors with constant relative risk aversion. The coefficients of relative risk aversion (RRA) range from 2 to 10. Annualized values of MUGs are reported.

Table 6: Annualized monetary utility gains (MUGs) of the created convenience yield sensitive portfolios for each of the commodities. MUGs are reported for different coefficients of relative risk aversion, ranging from RRA=2 to RRA=10. *Panel A* reports MUGs under the assumption of no transaction costs, while we also iexamine the results assuming typical transaction costs for small transaction size *Panel B* and large transaction sizes *Panel C* for the considered futures markets.

Panel A: No transaction costs								
	Metals			Grains			Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
RRA=2	4.94%	4.26%	4.65%	11.48%	9.81%	9.63%	0.33%	3.43%
RRA=4	4.93%	3.99%	4.49%	11.05%	9.17%	8.26%	-0.53%	0.07%
RRA=6	4.91%	3.67%	4.33%	10.63%	8.57%	7.06%	-1.41%	-3.02%
RRA=10	4.88%	2.78%	4.03%	9.83%	7.49%	5.03%	-3.31%	-8.88%
Obs	429	429	261	108	215	108	291	246
Panel B: Small transaction size								
	Metals			Grains			Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
RRA=2	4.41%	2.82%	3.21%	9.81%	8.80%	7.90%	-0.87%	2.06%
RRA=4	4.40%	2.55%	3.04%	9.38%	8.15%	6.53%	-1.73%	-1.27%
RRA=6	4.38%	2.22%	2.88%	8.96%	7.56%	5.33%	-2.62%	-4.36%
RRA=10	4.35%	1.33%	2.58%	8.16%	6.48%	3.30%	-4.52%	-10.22%
Obs	429	429	261	108	215	108	291	246
Tk in bp	1.1bp	3.0bp	(3.0bp)	3.5bp	2.1bp	3.6bp	2.5bp	2.8bp
Panel C: Large transaction size								
	Metals			Grains			Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
RRA=2	3.93%	1.52%	1.90%	9.04%	8.17%	6.61%	-1.07%	1.51%
RRA=4	3.92%	1.25%	1.74%	8.61%	7.53%	5.23%	-1.93%	-1.84%
RRA=6	3.90%	0.92%	1.58%	8.19%	6.93%	4.03%	-2.81%	-4.93%
RRA=10	3.87%	0.03%	1.28%	7.39%	5.85%	2.00%	-4.71%	-10.79%
Obs	429	429	261	108	215	108	291	246
Tk in bp	2.1bp	5.7bp	(5.7bp)	5.1bp	3.4bp	6.3bp	2.9bp	4.0bp

Note that for our calculation of MUGs, we consider different levels of transaction costs for creating and closing out the futures portfolios. Our results in Table 6 are presented for the assumption of no transaction costs (*Panel A*), typical transaction costs for small transaction sizes (*Panel B*), and, transaction costs referring to a large transaction size (*Panel*

C), in each of the examined markets. For further information on typical transaction costs in commodity markets, we refer to Marshall et al. (2012). Note that transaction costs for gold futures contracts are typically rather small and range from 1.1bp to 2.1bp, while for silver we have significantly higher transaction costs between 3.0bp and 5.7bp. Since we do not have information on the exact transaction costs for copper, in our analysis we use a conservative estimate of the costs and assume that they are similar to the transaction costs for silver. For grains, we have transaction costs between 2.1bp and 3.4bp for soybeans, between 3.5bp and 5.1bp for corn, while costs for transactions in wheat futures range from 3.6bp to 6.3bp. Finally, for energy markets transaction costs are between 2.5bp and 2.9bp for oil futures, and between 2.8bp and 4.0bp for natural gas futures contracts.

We find that for the assumption of no transaction costs, for metals MUGs range from 4.88% up to 4.94% for gold, from 2.78% up to 4.26% for silver and from 4.03% up to 4.65% for copper, depending on the assumed coefficients of RRA. For grains, we obtain even higher MUGs ranging from 9.83% to 11.48% for corn, while they are a bid lower for soybeans (7.49% - 9.81%) and wheat (5.03% - 9.63%). Overall, in particular for grains investors would require substantial returns in excess over a risk-free investment to be willing to switch from a portfolio strategy that invests in our convenience yield sensitive futures portfolio. For energy futures, we find that calculated MUGs are predominantly negative such that the created portfolios do not provide a viable alternative to investing in the risk-free asset.

Results remain qualitatively the same when transaction costs are being considered. Calculated MUGs for gold are only diminished by approximately 1% under the assumption of large transaction size, while they are more substantially reduced for silver and copper. Still, for any choice of the coefficient of RRA, annualized MUGs are still positive, such that investors in metals would require relatively high returns in excess over a risk-free investment to be willing to switch. For grains we get quite substantial annualized MUGs for the created convenience yield sensitive portfolios also when transaction costs are considered. For example, assuming a coefficient of RRA=6, we still get MUGs of 8.19% for corn, 6.93% for soybeans and 4.03% for wheat. On the other hand, for energy commodities, an investment in the risk-free asset is clearly preferable over the created convenience yield sensitive portfolios. Even for small transaction sizes, for any choice of RRA, MUGs are negative both for the created oil and natural gas futures portfolios.

Overall, we find substantial monetary utility gains for the constructed convenience yield sensitive portfolios for metals and grains, while MUGs are typically negative for oil and natural gas. While MUGs are reduced when transaction costs are included, investors would still require substantial returns in excess over a risk-free investment to be willing to switch from the created convenience yield sensitive futures portfolios to a risk-free investment.

3.3.2 Relation to Other Risk Factors

Finally, we have a look at correlations between returns from the constructed futures portfolios and other risk factors, see Table 7. We also examine returns from the created convenience yield sensitive portfolios across different classes of commodities.

A very nice result for investors is that returns from the constructed portfolios show rather low correlations across different commodities. For 26 out of 28 pairs, correlations between portfolio returns are below 0.3. Only for gold and silver, respectively wheat and gas, returns obtained from the convenience yield sensitive portfolios exhibit correlations around 0.6, respectively 0.49. These results point towards convenience yield risk premiums behaving quite

Table 7: Correlations between returns from the created convenience yield sensitive portfolios across different classes of commodities and against returns of the spot factor for the same commodity.

	Metals			Grains			Energy	
	Gold	Silver	Copper	Corn	Soybeans	Wheat	Oil	Gas
Gold	–	0.6209	0.0750	0.0958	0.0284	0.1092	-0.0693	0.0066
Silver	–	–	0.0167	0.0893	0.0860	0.0225	-0.0555	-0.0164
Copper	–	–	–	-0.2050	-0.1149	-0.1230	0.0072	-0.0097
Corn	–	–	–	–	0.0167	0.1639	0.0551	0.2887
Soybeans	–	–	–	–	–	-0.0313	0.2884	0.0210
Wheat	–	–	–	–	–	–	0.2134	0.4933
Oil	–	–	–	–	–	–	–	0.0160
Gas	–	–	–	–	–	–	–	–
Spot Factor	0.0827	0.1108	0.2821	0.2220	0.2554	0.5071	0.4357	0.6398

differently through time for the considered commodities. Interestingly, as illustrated in the last row of Table 7, returns from convenience yield sensitive portfolios do also not exhibit high correlations with spot returns from the same commodity. This is a particular nice feature of the constructed portfolios as it points towards the diversification potential of convenience yield risk premiums. The high positive returns, together with low correlations across different commodity classes, and against a spot factor, makes the created convenience yield sensitive portfolios very valuable for investors and risk managers in commodity markets.

4 Conclusions

This paper investigates convenience yield risk premiums in various commodity markets. While there is an extensive body of literature examining convenience yields in commodity markets, existing research provides only limited knowledge about the convenience yield risk premium. This is the first study to examine convenience yield risk premiums in various commodity markets, directly and in detail.

Based on two-factor (Gibson and Schwartz, 1990) and three-factor models (Schwartz, 1997), we use a direct approach to extract convenience yield risk premiums. We find that convenience yield risk premiums are positive and highly significant for several of the considered commodities. Our finding of positive convenience yield risk premiums is also robust across sub-period samples, different maturity of the considered futures contracts, and when interest rate risk is included into the analysis. However, the magnitude of the premium varies strongly between groups of commodities: while we find significant convenience yield premiums for metals and grains, results are insignificant for energy commodities.

Our study has important implications for the risk management of commodity positions and shows that convenience yield risk premiums can be very valuable for investors. For grains, a risk-averse investor realizes monetary utility gains over a risk-free investment of up to 11% per year from a corresponding trading strategy. Overall we suggest that high positive returns, together with low correlations across different commodity classes and spot returns, makes convenience yield risk premiums very valuable for investors and risk managers in commodity markets. We recommend further investigation of the premiums with respect to the market structure of the considered commodities in future work.

References

Ang, Andrew, and Geert Bekaert, 2002, International asset allocation with regime shifts, *Review of Financial Studies* 15, 1137–1187.

Bakshi, Gurdip, and Nikunj Kapadia, 2003, Delta-hedged gains and the negative market volatility risk premium, *Review of Financial Studies* 16, 527–566.

Basak, Suleyman, and Anna Pavlova, 2013, A model of financialization of co, Technical report, London Business School.

Basu, Devraj, and Joelle Miffre, 2009, Capturing the risk premium of commodity futures: The role of hedging pressure, Technical report, SKEMA Business School.

Bessembinder, Hendrik, 1992, Systematic risk, hedging pressure, and risk premiums in futures markets, *Review of Financial Studies* 5, 637–667.

Bessembinder, Hendrik, and Kalok Chan, 1992, Time-varying risk premia and forecastable returns in futures markets, *Journal of Financial Economics* 32, 169–193.

Bollinger, Thomas, and Axel H. Kind, 2010, Risk premiums in the cross-section of commodity convenience yields, Technical report, University of Basle.

Brennan, Michael J., 1991, The price of convenience and the valuation of commodity contingent claims, in *Stochastic Models and Option Values, D. Lund and B. Øksendal (eds.)* (North-Holland).

Carr, Peter, and Liuren Wu, 2009, Variance risk premiums, *Review of Financial Studies* 22, 1311–1341.

Casassus, Jaime, Pierre Collin-Dufresne, and Bryan R. Routledge, 2005, Equilibrium commodity prices with irreversible investment and non-linear technology, Working Paper 11864, National Bureau of Economic Research.

Casassus, Jaime, Peng Liu, and Ke Tang, 2012, Maximal affine models for multiple commodities: A note, Technical report, Pontificia Universidad Catolica de Chile.

Casassus, Jamie, and Pierre Collin-Dufresne, 2005, Stochastic convenience yield implied from commodity futures and interest rates, *Journal of Finance* 60, 2283–2331.

Chang, Eric C., 1985, Returns to speculators and the theory of normal backwardation, *Journal of Finance* 40, pp. 193–208.

Chng, Michael T., 2009, Economic linkages across commodity futures: Hedging and trading implications, *Journal of Banking & Finance* 33, 958–970.

Coval, Joshua D., and Tyler Shumway, 2001, Expected option returns, *Journal of Finance* 56, 983–1009.

Daskalaki, Charoula, Alexandros Kostakis, and George S. Skiadopoulos, 2012, Are there common factors in commodity futures returns?, Technical report, University of Piraeus.

de Roon, Frans A., Theo E. Nijman, and Chris Veld, 1998, Pricing term structure risk in futures markets, *Journal of Financial and Quantitative Analysis* 33, 139–157.

de Roon, Frans A., Theo E. Nijman, and Chris Veld, 2000, Hedging pressure effects in futures markets., *Journal of Finance* 55, 1437–1456.

Dusak, Katherine, 1973, Futures trading and investor returns: An investigation of commodity market risk premiums, *Journal of Political Economy* 81, 1387–1406.

Erb, Claude B., and Campbell R. Harvey, 2006, The strategic and tactical value of commodity futures, *Financial Analysts Journal* 62, 69–97.

Fama, Eugene F., and Kenneth R. French, 1987, Commodity futures prices: Some evidence on forecast power, premiums, and the theory of storage, *Journal of Business* 60, 55–73.

Gibson, Rajna, and Eduardo S. Schwartz, 1990, Stochastic convenience yield and the pricing of oil contingent claims, *Journal of Finance* 45, 959–976.

Gorton, Gary, and K. Geert Rouwenhorst, 2006, Facts and fantasies about commodity futures, *Financial Analysts Journal* 62, 47–68.

Gurkaynak, Refet S., Brian Sack, and Jonathan H. Wright, 2007, The U.S. treasury yield curve: 1961 to the present, *Journal of Monetary Economics* 54, 2291–2304.

Irwin, Scott H., and Dwight A. Sanders, 2011, Index funds, financialization, and commodity futures markets, *Applied Economic Perspectives and Policy* 33, 1–33.

Kaldor, Nicholas, 1939, Speculation and economic stability, *Review of Economic Studies* 7, 1–27.

Marshall, Ben R., Nhut H. Nguyen, and Nuttawat Visaltanachoti, 2012, Commodity liquidity measurement and transaction costs, *Review of Financial Studies* 25, 599–638.

Miffre, Joëlle, and Georgios Rallis, 2007, Momentum strategies in commodity futures markets, *Journal of Banking & Finance* 31, 1863–1886.

Prokopczuk, Marcel, and Yingying Wu, 2013, The determinants of convenience yields, Technical report, Zeppelin University and ICMA Center, University of Reading.

Rouwenhorst, K. Geert, and Ke Tang, 2012, Commodity investing, Technical report, Yale ICF Working Paper No. 06-12.

Schwartz, Eduardo S., 1997, The stochastic behavior of commodity prices: Implications for valuation and hedging, *Journal of Finance* 52, 922–973.

Schwartz, Eduardo S., and James E. Smith, 2000, Short-term variations and long-term dynamics in commodity prices, *Management Science* 46, 893–911.

Stoll, Hans A., and Robert E. Whaley, 2010, Commodity index investing and commodity futures prices, *Journal of Applied Finance* 20, 7–46.

Szakmary, Andrew C., Qian Shen, and Subhash C. Sharma, 2010, Trend-following trading strategies in commodity futures: A re-examination, *Journal of Banking & Finance* 34, 409–426.

Szymanowska, Marta, Frans A. de Roon, Theo E. Nijman, and Rob van den Goorbergh, 2013, An anatomy of commodity futures risk premia, *Journal of Finance* forthcoming.

Tang, Ke, and Wei Xiong, 2012, Index investment and the financialization of commodities, *Financial Analysts Journal* 68, 54–74.

Working, Holbrook, 1949, The theory of price of storage, *American Economic Review* 39, 1254–1262.