CONVENIENCE YIELDS IN BULK COMMODITIES: THE CASE OF THERMAL COAL

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ABSTRACT

This study advances the research on the convenience yield of bulk commodities with particular emphasis on thermal coal. We extend the option model of Milonas and Thomadakis (1997) to estimate thermal coal convenience yields using forward prices. We examine the business cycle of thermal coal in the presence of both demand and supply shocks and find that the convenience yield for thermal coal exhibits seasonal behavior. Convenience yields are negatively related to the inventory level of thermal coal despite the inventory not being co-located at the point of consumption while convenience yields are positively related to interest rates due to the business cycle. Our estimates of convenience yields for a bulk commodity such as thermal coal is consistent with results for other commodities such as base metals and oil where spot prices are more volatile than forward prices at low inventory levels. The result implies that the costs of storage are generally less than the operating costs associated with changes to production capacity so thermal coal producers prefer to stockpile the commodity rather than adjust production in response to changes in demand.

JEL: C53, G14, Q41

KEY WORDS: Commodities, Convenience Yield, Forward Markets, Thermal Coal, Storage, Options, Contango.

INTRODUCTION

The ability to trade financially settled contracts for seaborne thermal coal has undoubtedly increased the efficiency of the global coal market. Annually more than 560 million tonnes of coal are traded on the seaborne market and the growth in the volume of forward contracts for this commodity since 2002 has enabled producers and consumers of thermal coal to smooth out fluctuations in price exposure. This capability is critical for the highly seasonal European power market and the liquid trading of forward electricity contracts. Over 180 million tonnes of thermal coal is imported to Europe annually from the producing regions of South Africa, Colombia, Indonesia and Russia and consumers are able to hedge their exposure through coal swap contracts whose prices are subsequently tracked via a number of key price indexes.

Thermal coal is a strategic resource which is primarily used for power production, although it is also consumed in cement manufacturing and other industries. The security of supply of thermal coal is critical for the efficient operation of Europe's electricity market. The purpose of this study is to analyze the spot and forward market for thermal coal and provide estimates of convenience yield and volatility through time, while correcting for major sources of seasonality. We find that the observed convenience yield is a surrogate for the volatility level in the thermal coal spot market and changing dynamics in the supply of, and demand for, the commodity.

The concept of convenience yield originates from Kaldor (1939) and was further developed under the theory of storage in Brennan (1958). The theory claims that goods in stock not sold forward have an unobservable value from the flexibility of use, since a market participant owning these goods has the 'convenience' to make use of them. For this reason the observable cost of carry of a stored commodity (foregone interest and the cost of physical storage) must be reduced by a so-called availability premium.

Since buying on the spot market and selling forward is a riskless trade (cash and carry), the (net) cost of carry must equal to the difference between the forward price and the spot price.

When we differentiate the existing body of convenience yield literature by commodity type we discover that bulk commodities such as thermal coal have so far received little attention. This is important to note since comparable studies for other commodities are of limited value for the bulk commodity market. This is because thermal coal is a resource with particular features and even the comparison to other energy commodities such as oil or natural gas, are of limited value. Transportation costs for seaborne thermal coal are generally higher and require significant infrastructure through the value chain. This can lead to persistent demand-supply imbalances when the capacity limit of the transport system is reached resulting in regional price differentials. Besides this, storage of thermal coal is not necessarily co-located with the thermal coal consumer and may therefore incompatible with the notion of convenience. Convenience yield studies in other commodity markets are thus not directly transferable to the coal market due to these unique characteristics. This study uses detailed data on the capacity of the transport network, local production volumes and operating costs for the storage, loading and transport nodes at mine and port facilities. Unlike other empirical studies of supply curves and the production smoothing of inventories we employ actual costs as reported by asset operators which avoids a broad analysis of inventory management where the cost structure is simply assumed.

Extending the option model of Milonas and Thomadakis (1997) to value convenience yields, we find that convenience yields are negatively related to the inventory level of the underlying thermal coal and are positively related to interest rates due to the business cycle. A positive convenience yield can be best represented as a long position in an embedded call option on the commodity. Our convenience yields estimates are consistent with Fama and French (1988) which illustrates that the spot price of thermal coal is more volatile than the forward price at low inventory levels which verifies the Samuelson (1965) hypothesis for bulk commodities.

This paper first discusses commodity markets and thermal coal and then introduces the data. The paper will then outline the model and develop the testing methodology. Finally we present the results and offer some concluding remarks.

LITERATURE REVIEW AND BACKGROUND

Because a commodity can be consumed, its price is a combination of future asset and current consumption values. However, unlike financial assets, storage of energy products is costly and sometimes constrained by infrastructure design. Physical ownership of the commodity carries an associated flow of services and the agent has the option of flexibility with regards to consumption as well as reduced risk of commodity shortages. On the other hand the decision to postpone consumption implies a storage expense. Thermal coal producers operate in an environment where production cannot be altered easily and storage of the commodity is not necessarily co-located at the point of consumption. Furthermore the supply response to changes in demand is notoriously ‘sticky’ implying that production generally continues at a similar rate for some time despite medium-term changes in demand.

In equilibrium, backwardation implies that immediate ownership of the physical commodity entails some benefit or convenience which deferred ownership (via a long forward position) does not. This benefit, expressed as a rate, is termed the ‘convenience yield’. A convenience yield is natural for goods, like art or land, that offer exogenous rental or service flows over time. However, substantial convenience yields are also observed in bulk commodities, such as coal which are consumed at a single point in time. Intuitively, the convenience yield corresponds to the dividend yield for stocks.

The theory of storage (Brennan, 1958) explains convenience yields in terms of an embedded timing option. In particular, the holder of a storable commodity can decide when to consume it. If it is optimal to store a commodity for future consumption, then it is priced like an asset, but if it is optimal to consume it immediately, then the commodity is priced as a consumption good. Thus, a commodity's spot price is the maximum of its current consumption and asset values (Routledge, Seppi and Spatt, 2000). Inventory decisions are important for commodities because, by influencing the relative current and future scarcity of the good, they link its current (consumption) and expected future (asset) values. This is unlike equities and bonds where outstanding quantities are generally fixed.

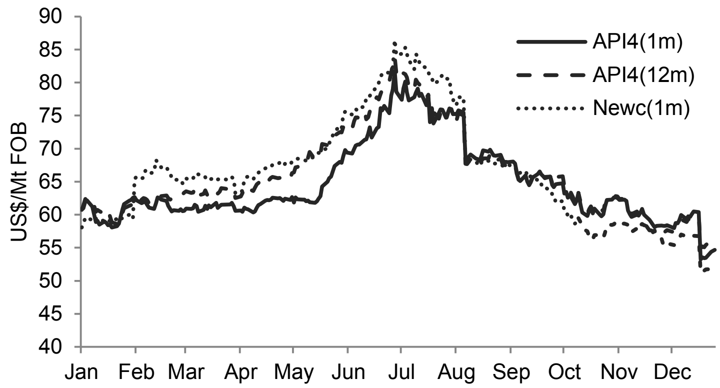
Most studies that estimate convenience yields use a cost-of-carry model where the convenience yield is treated as an exogenous variable. Brennan (1986) showed that convenience yields follow a mean-reverting process while Gibson and Schwartz (1990) used a cost-of-carry model with stochastic mean-reverting convenience yields, assuming the presence of an exogenously defined measure of convenience. Generally, models for convenience yields assume that storage costs are zero (Fama and French, 1988) or are simply assumed (Milonas and Henker, 2001). In particular Fama and French (1988) used the interest-adjusted basis as a proxy which avoids the need to estimate storage costs, to develop the relationship between convenience yield and inventory levels. Taking an alternative approach Milonas and Thomadakis (1997) extended the option approach of Heinkel, Howe and Hughes (1990) using a formulation of the Black–Scholes model to estimate convenience yields. Although they model convenience yields as call options they ignore storage costs which can result in theoretically unjustified negative convenience yields.

We adapt a version of the Milonas and Thomadakis (1997) option pricing model to examine the behavior of convenience yields with supply and demand shocks for thermal coal using free on board (FOB) prices from Richard's Bay, South Africa. Figure 1 illustrates the weekly average spot price of the price index for thermal coal from Richard's Bay, known as API4, from 2003 to 2010. A plot of Newcastle FOB prices from Australia is also provided to illustrate the global nature of the seaborne thermal coal market and the relationship between coal prices from different exporting regions.

Thermal coal prices tend to peak in July in preparation for the demand growth for imports to Europe in winter as well as the easing of the monsoon in India where the major ports begin to re-open. The lowest prices for thermal coal generally occur in the northern winter. As with the crude oil and natural gas markets, the behavior of thermal coal is affected by both seasonality and business cycles.

We employ an extension of the Milonas and Thomadakis (1997) option pricing approach because the behavior of thermal coal prices are affected by seasonal business cycles and so modeling price behavior using mean reversion and assuming convenience yields are an exogenous mean-reverting variable (Gibson and Schwartz, 1990) may not necessarily be appropriate. To estimate convenience yields we consider the presence of unexpected demand-supply shocks and the business cycle. We define the business cycle as the sequence of supply and demand equilibrium traced to a point of relative disequilibrium at the height of demand through to the restoration of equilibrium. The thermal coal business cycle is thus from around March to October.

Figure 1: Mean of API4 (Richards Bay, South Africa) and Newcastle (Australia) Thermal Coal FOB 2003-10 US$/Mt.



DATA AND OBSERVATIONS

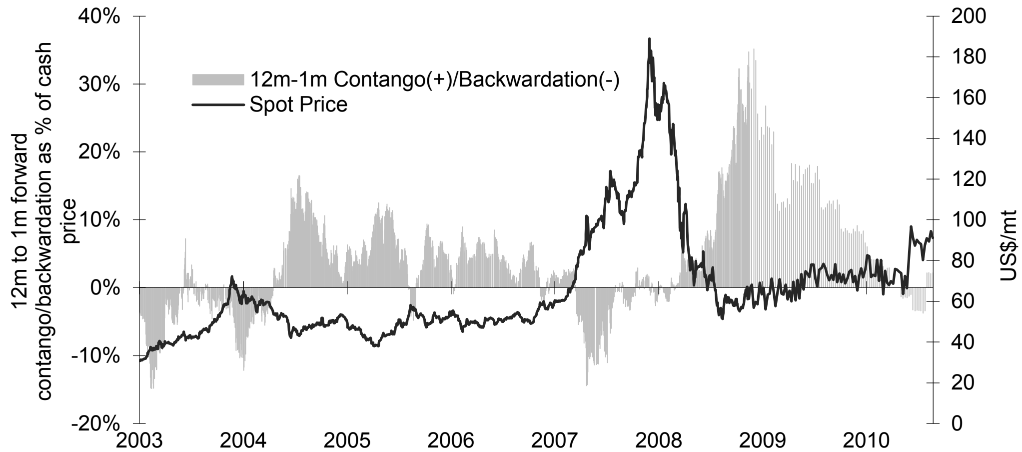
The main indexes used for the trading, clearing and settlement of thermal coal, jointly calculated and published by Argus and IHS McCloskey, are the API2 and API4 indexes. The API2 index is the international price benchmark for coal imported to north-western Europe while the API4 index is the international price benchmark for coal exported from the Richards Bay Coal Terminal (RBCT) in South Africa. The API4 forward curve is constructed as an average of the Argus FOB Richards Bay assessment and McCloskey's FOB Richards Bay marker for coal with certain minimum quality specifications. The API4 index is the most appropriate proxy for Atlantic coal prices to the European market because it is more representative of the true cost of coal as a consumption good, it is immune to changes in the forward freight market and it is also immune to supply alternatives from producers that enjoy a freight cost advantage into Europe. The implied inclusion of freight costs in the API2 index are difficult to extract in a meaningful way and therefore a true FOB forward curve is a better representation for this analysis. Table 1 provides a summary of the descriptive statistics of the data used in our analysis.

Table 1: Descriptive Statistics of the Data

	1m-API4 (US$/t)	3m-API4 (US$/t)	12m-API4 (US$/t)	3m T-bill (%)	Inventory (tonnes)
n	1589	1589	1589	1589	1589
Mean	64.98	65.05	66.50	2.63	3.11
Std Dev	29.43	29.11	28.56	1.66	0.68
Skewness	1.94	1.95	1.88	0.07	-0.16
Kurtosis	3.41	3.47	3.45	-1.44	-0.59
Max	189.00	189.80	189.05	5.05	5.00
Min	30.80	30.75	29.65	0.00	1.76

Forward price data for thermal coal is free on board (FOB) Richards Bay (API4) at 1-month, 3-month and 12-month tenors in US$ per metric tonne (US$/t. Data also includes 3-month US T-bills (%) and inventory levels at RBCT in metric tonnes.

Figure 2: API4 Thermal Coal 12-month forward Price Differential to Spot Price in US$ 2003-10



Source: McCloskey.

Figure 2 shows the contango(+)/backwardation(-) relationship against spot prices from 2003-2011. The 12m rate is used here as a proxy for the longer end of the curve (12-month and 24-month forward prices are highly correlated: > 0.89 over 2003-2011) and the 24-month tenor contracts were relatively illiquid prior to 2005.

If the convenience yield is high enough, the observed forward price will be less than the spot price. This occurs quite frequently in oil and gas markets where the premium for immediacy is very real. If however, this relationship does not hold and the forward price is much higher than spot when taking into account high working capital costs (funding and storage), the convenience yield converges to zero.

In addition to the cost-of-carry theory, Brennan (1958) established an equilibrium model for commodity inventories which assumes that the marginal convenience value of a good is a decreasing function of its aggregate inventory in the economy. Brennan therefore suggests a negative relationship between convenience yield and stock levels, which has been verified empirically for some commodities (Fama and French, 1988; Gibson and Schwartz, 1990; Modjtahedi and Movassagh, 2005) and will be tested for the bulk commodity markets in the following analysis.

THE MODEL

Let $F(t,T)$ be the forward price at time *t* for delivery of the commodity at time *T* and let $S(t)$ be the spot price. According to the theory of storage under an arbitrage-free framework the return from purchasing the commodity at *t* and selling it for delivery at T, $F(t,T) - S(t)$, will equal the net cost of holding the commodity computed as the interest forgone during storage $S(t)R(t,T)$ plus the marginal storage cost $W(t,T)$ minus the marginal convenience yield $C(t,T)$:

$$F(t,T) - S(t) = S(t)R(t,T) + W(t,T) - C(t,T). \quad (1)$$

This notation follows Fama and French (1987). In a normal market forward prices should exceed spot prices by an amount that is equivalent to interest costs and storage costs and any deviation from this is explained via the so-called convenience yield. This quantity is a marginal spread component which can be modeled as an option on a positive spread between spot and forward prices.

The forward price at date *t* is determined by current storage levels and the expected demand and production levels at *T*. When the market experiences higher demand or reduced supply, storage falls to zero. If production at T is known with certainty then we expect a direct but negative relationship between the forward price and storage levels which sets an upper bound for the forward price. When supply and demand is in perfect equilibrium we expect the convenience yield to equal zero however when equation (1) holds we obtain $C(t,T) > 0$. A temporary shock in demand or supply conditions during the business cycle will cause a change in storage levels which in turn affects the spot price. This will give rise to a risk premium for possession of the commodity resulting in a positive convenience yield.

Fama and French (1988) consider the behavior of the convenience yield on an interest-adjusted basis which avoids the need to directly estimate the convenience yield. But this approach fails to provide a complete picture of the true convenience yield. For thermal coal, the storage cost implied in (1) is not difficult to estimate and so observing the true convenience yield is feasible. Using the alternative approach of Milonas and Thomadakis (1997) who treat the convenience yield as an option, we set the spot price as the underlying variable and the price of a 3-month forward contract as the exercise price. Under a cost-of-carry framework with zero storage cost, the convenience yield is the difference between the net cost of carrying a nearby and a distant futures contract observed at time 0,

$$CY(0,T) = \text{Max}(F(0,t) - F(t,T), 0). \tag{2}$$

The convenience yield from t to T observed at 0 at the commencement of the business cycle ignores the cost of storage. Therefore including the storage cost $W(t,T)$ permits equation (2) to be defined as

$$CY(0,T) = \text{Max}(F^{\star}(0,t) - F(t,T), 0). \tag{3}$$

where $F^{\star}(0,t) = F(0,t) + W(0,T)$ assuming $t = 0$.

Since both the spot price and the forward price (exercise price) are stochastic we assume they both follow standard diffusion processes which can be expressed as

$$dF(0,t) = \mu_{1m}F(0,t)dt + \sigma_{1m}F(0,t)dz_{1m},$$
$$dF(t,T) = \mu_{3m}F(t,T)dt + \sigma_{3m}F(t,T)dz_{3m},$$

where the subscripts *1m* and *3m* represent the 1- and 3-month tenor for each forward contract respectively. We make the important assumption that the diffusion terms dz_t are uncorrelated. The associated boundary condition is defined as

$$F(0,t)\text{Max}(F_T - 1,0), \tag{4}$$

where $F_T = F^{\star}(0,t)/F(t,T)$. Applying Ito's lemma yields the following closed form solution

$$CY(0,T) = F^{\star}(0,t)N(d_1) - F(t,T)N(d_2), \tag{5}$$

where

$$d_1 = \frac{\ln(F_T) + \sigma_c^2\tau/2}{\sigma_c\sqrt{\tau}},$$
$$d_2 = d_1 - \sigma_c\sqrt{\tau} = \frac{\ln(F_T) - \sigma_c^2\tau/2}{\sigma_c\sqrt{\tau}},$$

and

$$\sigma_c^2 = \sigma_{F^{\star}(0,t)}^2 + 2\sigma_{F^{\star}(0,t)}\sigma_{F(t,T)}\rho_{F^{\star}(0,t)F(t,T)} + \sigma_{F(t,T)}^2, \tag{6}$$

where σ_i is the volatility of each forward contract i, ρ_{ij} is the correlation coefficient of both forward contracts and τ is the period between the 1-month and the 3-month contracts. This derivation relies on the price of a traded asset as the strike price which resolves the unknown variable problem of the option approach (Lin and Duan, 2007).

RESULTS

We use the 1-month API4 price to represent the spot price of thermal coal since it is the nearest contract for delivery. The 3-month forward API4 price is used to represent the forward price as it is the forward contract with the highest liquidity. For the risk-free rate we use 3-month US Treasury bill yields. We obtained actual storage costs at Richard's Bay Coal Terminal (RBCT) for the storage cost component of the model. We also make a quality adjustment to the coal at a depletion rate of 120kcal/kg per 3-month period, which acts as a linear price discount for a parcel of coal. No other quality adjustments were made. A non-zero storage cost does not greatly alter the observed behavior in the implied convenience yield curve over time, since storage fees are a small portion of the total cost of thermal coal (US$2-3/t annually).

Convenience yields are calculated on a daily basis throughout the observation month and then averaged over each month. We calculate the monthly convenience yields from January to December and use July, when spot prices peak, as the shock month to estimate convenience yields. We apply a simple regression analysis to examine the relationship between convenience yields and inventory levels, covariance and interest rates and the convenience yield computed using the option formulation of equation (5) and the convenience yield computed using the traditional cost of carry formulation of equation (1). The regression equations are

$$CY_{t,T}^{Option} = \beta_0 + \beta_1 I_{t-1} + \varepsilon_t, \quad (7)$$

$$CY_{t,T}^{CoC} = \beta_0 + \beta_1 I_{t-1} + \beta_2 \sigma_{c,t}^2 + \beta_3 rf_t + \varepsilon_t, \quad (8)$$

where I_{t-1} is the one-month lagged inventory level, σ_c^2 is the covariance of the spot and forward contract prices as per equation (6) and rf_t is the risk-free rate at time *t*. The theory of storage suggests that holding inventory becomes more costly during periods of high interest rates and therefore, convenience yields should be positively related to the risk-free rate as well as the covariance of the spot and forward prices.

Table 2 presents the convenience yields calculated based on the call option $CY_{t,T}^{Option}$ and cost-of-carry $CY_{t,T}^{CoC}$ models. The results show that the values of the convenience yields estimated from the options model are higher than those from the cost-of-carry model, implying the strategic and management flexibility valued using the options approach.

These results give support to the hypothesis of Brennan (1958) and suggest that the convenience yield is highest when inventories are low. That is to say, the benefit of holding inventories is greatest during periods of relative scarcity or heightened demand. In efficient pure contango markets the convenience yield should be close to zero. If inventory levels are small relative to the amount consumed of the commodity, the risk of a supply shock raises the convenience yield. If such risks are high enough, it is expected that the forward market will revert to a backwardated market, often suddenly. Under such conditions, it is also possible that arbitrage conditions may weaken or may even break down. It is incorrect to assume, out of context, that rising inventories means an overhang of supply that translates into lower prices until the market clears. Note that forward markets are priced on the principle of equivalence.

Table 2: Linear Regression of Convenience Yields for Thermal Coal (API4) 2004-10

Month	Model	β_0	β_1	β_2	β_3	Adj R^2	F
Jan	$CY_{1m,3m}^{Option}$	0.054	-0.017			0.300	46.780
		(0.554)	(-0.017)				
	$CY_{1m,3m}^{CoC}$	0.148***	-0.009***	2.245***	-0.006***	0.315	17.409
		(10.866)	(-2.116)	(6.088)	(-3.453)		
Feb	$CY_{1m,3m}^{Option}$	0.042***	-0.010***			0.099	12.818
		(5.633)	(-3.580)				
	$CY_{1m,3m}^{CoC}$	0.123***	-0.009***	1.150***	-0.003***	0.304	16.579
		(17.281)	(-3.274)	(4.283)	(-2.679)		
Mar	$CY_{1m,3m}^{Option}$	0.012***	-0.013***			0.079	10.233
		(3.930)	(-3.199)				
	$CY_{1m,3m}^{CoC}$	0.125***	-0.003***	2.326***	0.004***	0.653	67.985
		(18.829)	(-10.194)	(9.220)	(6.782)		
Apr	$CY_{1m,3m}^{Option}$	0.017***	-0.015***			0.252	34.060
		(6.919)	(-5.836)				
	$CY_{1m,3m}^{CoC}$	0.099***	-0.009***	2.211***	0.011***	0.773	91.932
		(12.972)	(-10.730)	(3.333)	(15.299)		
May	$CY_{1m,3m}^{Option}$	0.001	0.000			0.004	1.158
		(0.888)	(-1.319)				
	$CY_{1m,3m}^{CoC}$	0.167***	-0.026***	7.107***	0.014***	0.589	51.681
		(7.934)	(-6.043)	(7.861)	(11.406)		
Jun	$CY_{1m,3m}^{Option}$	0.027***	-0.046***			0.112	9.406
		(2.773)	(-3.127)				
	$CY_{1m,3m}^{CoC}$	0.114***	-0.006***	4.331***	0.004***	0.947	63.253
		(34.902)	(-3.820)	(29.445)	(6.094)		
Jul	$CY_{1m,3m}^{Option}$	0.074***	-0.021***			0.170	23.360
		(5.264)	(-4.833)				
	$CY_{1m,3m}^{CoC}$	0.056***	0.010	1.089***	0.006***	0.148	7.330
		(2.021)	(1.062)	(4.593)	(2.872)		
Aug	$CY_{1m,3m}^{Option}$	0.026***	-0.046***			0.127	17.038
		(4.867)	(-4.128)				
	$CY_{1m,3m}^{CoC}$	0.073***	-0.015***	4.852***	0.029***	0.431	28.718
		(8.328)	(-8.172)	(7.004)	(8.964)		
Sep	$CY_{1m,3m}^{Option}$	0.011***	-0.061***			0.091	7.062
		(2.264)	(-3.248)				
	$CY_{1m,3m}^{CoC}$	-0.111***	0.017***	-1.623***	0.007***	0.853	75.776
		(-5.924)	(9.480)	(-10.525)	(4.250)		
Oct	$CY_{1m,3m}^{Option}$	0.022***	-0.035***			0.106	11.585
		(3.797)	(-3.404)				
	$CY_{1m,3m}^{CoC}$	-0.105***	0.018***	6.881***	-0.015***	0.488	29.225
		(-4.883)	(6.965)	(7.342)	(-8.345)		
Nov	$CY_{1m,3m}^{Option}$	0.059***	-0.059***			0.186	25.149
		(5.806)	(-5.015)				
	$CY_{1m,3m}^{CoC}$	0.269***	-0.009***	-1.481***	0.004	0.356	20.540
		(3.958)	(-2.548)	(-6.897)	(0.845)		
Dec	$CY_{1m,3m}^{Option}$	0.015***	-0.014***			0.156	20.611
		(5.227)	(-4.540)				
	$CY_{1m,3m}^{CoC}$	-0.048***	0.015***	1.553***	0.017***	0.737	99.975
		(-4.466)	(6.778)	(6.442)	(11.853)		

*Convenience yields are computed using the options estimate and the cost of carry estimate on inventory, volatility and the risk-free rate by month. t-statistics in parentheses, *** denotes significance at the 1 percent level.*

In a perfectly balanced market, a consumer is indifferent between buying a physical commodity now and storing it for later consumption, and buying it for future delivery and letting the producer pay for the storage costs. This situation, also known as full carry, seldom applies in practice. The world's thermal coal consumers, mainly power producers, cannot afford to run out of inventory and they therefore pay for the 'convenience' of having excess supplies available. This yield can be viewed as the commodity buyer's insurance payment for supplies. It also represents the producer's cost of hedging by selling forward contracts for the commodity. For bulk commodities such as coal where the cheapest place of storage is generally with the producer, the convenience yield measure could be quite high.

Table 3 illustrates the convenience yields from the shock month of July to the final month of the cycle in November. The negative correlation between the convenience yield and the inventory level suggests that it is closely linked to business cycle, as the convenience yield is unrelated to the thermal coal stocks in Europe.

Table 3: Estimated Convenience Yields of Holding Period 2004-10

Jul-Oct	$CY_{1m,3m}^{Option}$	$CY_{1m,3m}^{CoC}$
2004	0.0779	0.0710
2005	0.0874	0.0855
2006	0.1198	0.1041
2007	0.0755	0.0783
2008	0.0208	0.0252
2009	0.0073	0.0289
2010	0.0691	0.0595
Total	0.0654**	0.0646**
	(4.448)	(5.8763)
Correlation ρ	-0.422***	-0.123**
p-value	<0.001	0.043

*Convenience yields are computed from the shock month of July to October (final month of the cycle). t-statistics in parentheses, *** and ** denotes significance at the 1 percent and 5 percent levels respectively.*

The theory of storage also predicts that, at a low inventory level, forward prices vary less than spot prices while at a high inventory level, spot prices and forward prices exhibit similar variability. Fama and French (1988) supported Samuelson's hypothesis by examining the interest-adjusted basis of base metals. The convenience yield declines at higher inventory levels and rises at low inventory levels. To test the Samuelson (1965) hypothesis, we adopt the same approach as Fama and French (1988) and perform a regression of forward prices against spot prices.

Next we conducted a regression of forward prices against spot prices using

$$ln\left(F_{t,T}/F_{t-1,T-1}\right) = \alpha_0 + \alpha_1 ln(S_t/S_{t-1}) + \varepsilon_t, \quad (9)$$

categorized by high and low convenience yields for both the full sample and also for the shock month (July) data. The data was split by periods of high convenience yield and low convenience yield and the regression analysis then applied to estimate the α_1 coefficients. Table 4 shows the results.

We find that high convenience yields have smaller average values for the coefficients while low convenience yields have average coefficient values close to one. This implies that at a low inventory level the spot price of thermal coal varies more than the forward price with a high convenience yield derived using the option model approach, while at high inventory levels the spot and forward price of thermal coal have similar variability with smaller convenience yields. These results are consistent with the hypothesis of Samuelson (1965) and the results of Fama and French (1988).

Table 4: Regression of Forward Prices against Spot Prices 2004-10

Sample	$CY^{Option}_{1m,3m}$ level	$\overline{CY}^{Option}_{1m,3m}$	α_1
Full	High	0.0572***	0.818***
		(5.4199)	(2.7031)
	Low	0.0086***	0.9149***
		(3.4971)	(42.557)
July as shock	High	0.0600***	0.765***
		(4.3043)	(34.677)
	Low	0.0063***	0.9855***
		(5.5945)	(89.026)

*Regression is estimated using $ln(F_{t,T}/F_{t-1,T-1}) = \alpha_0 + \alpha_1 ln(S_t/S_{t-1}) + \varepsilon_t$ split by high and low convenience yields for the full sample and for the July data. t-statistics in parentheses, *** denotes significance at the 1 percent level.*

When contracts are far away from maturity they are thinly traded and exhibit low volatility. As the maturity nears, both trading volume and volatility increase. Specifically, spot contracts of thermal coal are usually used for balancing week-to-week needs and consequently exhibit high volatility. This result therefore suggests that the term structure of thermal coal forward volatility is monotonically decreasing.

CONCLUSION

The goal of this paper was to show that for bulk commodities, convenience yields are negatively related to the underlying inventory level and are positively related to interest rates over the business cycle. Using free-on-board thermal coal forward price data over 2003-10 from Richards Bay Coal Terminal (API4) and actual incurred storage costs, our convenience yield estimates were shown to be consistent with the Fama and French (1988) outcomes for more liquidly-traded base metals futures contracts. We have shown that using an extended version of the Milonas and Thomadakis (1997) call option model, the convenience yield for thermal coal exhibits seasonality under the influence of the business cycle. The results show that the negative correlation between the convenience yields for API4 thermal coal and the inventory level at Richard's Bay becomes more significantly negative when examined during periods of high spot prices, allowing for business cycle effects. This demonstrates that spot prices of bulk commodities are more volatile than forward prices at low inventory levels and verifies that the Samuelson (1965) hypothesis applies for bulk commodities. The results also illustrate that the timing of the business cycle is critical to the calculation of the thermal coal convenience yield.

While interest rates are affected by economic activity they in turn affect convenience yields of thermal coal. We find evidence that supports the Samuelson (1965) hypothesis that spot and forward price variations of thermal coal are similar when a supply shock occurs during higher inventory levels and that spot prices will be more variable than the forward prices at lower inventory levels. Deferred forward contracts are less volatile than near maturity contracts because as a contract draws nearer to maturity, producers and consumers are forced to react more quickly to information shocks and thus the term structure of thermal coal forward volatility is shown to be monotonically decreasing. The implications of the research are that thermal coal producers clearly prefer to stockpile the commodity rather than adjust production in response to changes in demand which implies that the costs of storage are less than the operating costs associated with changes to production capacity.

This approach has a number of limitations which include the usual assumptions of normally-distributed commodity price returns as well as constant implied volatility and a constant risk-free rate as inputs to the extended Black-Scholes option pricing model. This analysis also relies on a liquidly traded forward freight market for bulk commodities to ensure the business cycle is relatively frictionless. Forward freight contracts from Richards Bay are generally liquid but there have been periods of low activity which indirectly affects implied forward prices for thermal coal. The level of inventory which underpins the results from the study also relies on frictionless infrastructure to deliver thermal coal to the port from the mines. However there have been delivery bottlenecks over the observation period which may affect the assumed inventory level.

Future research should seek to verify these findings for other bulk markets in the presence of seasonality such as agricultural commodities, alumina and iron ore. Future research may also incorporate stochastic volatility and price mean reversion to more effectively model bulk commodity prices and price volatility to fully test the relationship between convenience yields and inventory over the business cycle.

REFERENCES

Brennan, M.J. (1958) "The supply of storage," *American Economic Review*, 48, 50-72.

Fama, E. and French, K. (1987) "Commodity futures prices: some evidence on forecast power, premiums and the theory of storage," *Journal of Business* 60: 55-74.

Fama, E. and French, K. (1988) "Business cycles and the behavior of metals prices," *Journal of Finance* 43: 1075-1793.

Gibson, R. and Schwartz, E.S. (1990) "Stochastic convenience yield and the pricing of oil contingent claims," *Journal of Finance* 45: 959-976.

Heinkel, R., Howe, M. and Hughes, J.S. (1990) "Commodity convenience yields as an option profit," *Journal of Futures Markets* 10: 519-533.

Kaldor, N. (1939) "Speculation and economic stability," *Review of Economic Studies* 7: 1-27.

Lin, W.T. and Duan, C.W. (2007) "Oil convenience yields estimated under demand/supply shock," *Review of Quantitative Finance and Accounting* 28: 203-225.

Milonas, N.T. and Thomadakis, S.B. (1997) "Convenience yields as call options: an empirical analysis," *Journal of Futures Markets* 17: 1-15.

Milonas, N.T. and Henker, T., (2001) "Price spread and convenience yield behavior in the international oil market," *Applied Financial Economics*, 11, 23-36.

Modjtahedi, M. and Movassagh, N. (2005) "Natural gas futures: bias, predictive performance and the theory of storage," *Energy Economics* 27: 617-637.

Routledge, B.R., Seppi, D.J. and Spatt, C.S. (2000) "Equilibrium forward curves for commodities," *Journal of Finance* 55(3): 1297-1338.

Samuelson, P.A. (1965) "Proof that properly anticipated prices fluctuate randomly," *Industrial Management Review* 6: 41-50.

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