Albuquerque, Thiago de Orlando.
The Theory of Storage and The Volatilities of Commodities Prices / Thiago de Orlando e Albuquerque. – 2009.
57 f.

Orientador: Rafael Felipe Schiozer.
Dissertação (mestrado) - Escola de Economia de São Paulo.

1. Bolsa de mercadorias - Preços. 2. Preços - Previsão. 3. Estoques. I. Schiozer, Rafael Felipe. II. Dissertação (mestrado) - Escola de Economia de São Paulo. III. Título.

CDU 339.172

THIAGO DE ORLANDO E ALBUQUERQUE

THE THEORY OF STORAGE AND THE VOLATILITIES OF COMMODITIES PRICES

Dissertação apresentada à Escola de Economia de São Paulo da Fundação Getúlio Vargas como requisito para obtenção do título de Mestre em Finanças e Economia de Empresas

Campo de conhecimento:
Finanças

Orientador Prof. Dr. Rafael F. Schiozer

SÃO PAULO
2009

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Finanças Corporativas

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DEDICATÓRIA

Aos meus pais que ao longo de toda a minha vida acadêmica me apoiaram, deram acesso às melhores instituições e me ensinaram da importância da dedicação aos estudos;

À Juliana Campos, eterna amiga e grande companheira que com seu apoio incondicional me ajudou a superar as dificuldades desta jornada que, ao menos por hora, encerra minha trajetória acadêmica, dedico este trabalho.

AGRADECIMENTOS

Ao Professor Dr. Rafael F. Schiozer, pela orientação, ensinamentos e confiança a mim dispensados em um momento de grandes dificuldades, para a elaboração do presente trabalho, assim como pela amizade conquistada;

Aos Professores do Mestrado Profissional em Finanças e Economia Empresarial pelos conhecimentos compartilhados;

Aos amigos que tanto me apoiaram e me deram força neste desafio e a todos que direta ou indiretamente contribuíram para a realização deste trabalho.

ABSTRACT

This paper extends the methodology of Fama and French (1988) to test the hypothesis described in the theory of storage that the marginal convenience yield on inventory falls at a decreasing rate as inventory increases. As Samuelson (1965) describes, the theory implies that spot and futures price variations will be similar when inventories are high, but futures prices are less variable than spot prices when inventory is low. I test the hypothesis by examining the relative variation of spot and futures prices for WTI crude oil, aluminum and copper based on the Fama and French (1988) method that uses the interest-adjusted basis as a proxy of high and low inventories. Results for the metals are, in general, consistent with the theory of storage, even testing for subperiods, including the boom and burst in the prices of commodities occurred in 2005-2008. For the price of oil, however, some of the results do not hold, especially for the longer contracts, showing that other factors rather than stocks, supply and demand (e.g. speculation) may be driving spot and/or future prices.

RESUMO EXPANDIDO

Esse estudo estende a metodologia de Fama e French (1988) para testar a hipótese derivada da Teoria dos Estoques de que o *convenience yield* dos estoques diminui a uma taxa decrescente com o aumento de estoque. Como descrito por Samuelson (1965), a Teoria implica que as variações nos preços à vista (spot) e dos futuros (ou dos contratos a termo) serão similares quando os estoques estão altos, mas os preços futuros variarão menos que os preços à vista quando os estoques estão baixos. Isso ocorre porque os choques de oferta e demanda podem ser absorvidos por ajustes no estoque quando este está alto, afetando de maneira similar os preços à vista e futuros. Por outro lado, quando os estoques estão baixos, toda a absorção dos choques de demanda ou oferta recai sobre o preço à vista, uma vez que os agentes econômicos têm pouca condição de reagir à quantidade demandada ou ofertada no curto prazo. No entanto, uma vez que os agentes podem reagir a choques no médio e longo prazo, alterando sua matriz de inputs (consumidores) ou ajustando a produção (produtores) de acordo com o novo equilíbrio de oferta e demanda, os preços futuros variarão menos que os preços à vista quando os estoques estão em níveis baixos. Eu testo essa hipótese examinando a variação relativa dos preços à vista e futuro para o petróleo tipo West Texas Intermediate (WTI), para o alumínio e cobre, no período de 1990 a 2008, baseado na metodologia de Fama e French (1988), que usa a base ajustada à taxa de juros (*interest-adjusted basis*) como proxy para o nível de estoques. Os resultados para os metais básicos são consistentes com a Teoria dos Estoques e se mantém para os sub-períodos testados, incluindo o período de explosão e queda de preços verificado de 2005 a 2008. Já para o petróleo, no entanto, os resultados são apenas parcialmente consistentes com a Teoria, o que pode indicar que outros fatores além de estoques, oferta e demanda (por exemplo, ação especulativa dos agentes) pode influenciar os preços à vista e futuros.

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SUMÁRIO

1 INTRODUCTION

Understanding the behavior of commodities prices is a very important and hard task for producers, consumers and investors involved in the commodity market. Producers must use forecasts to better manage their investment decisions. Most of the commodities industries are capital intensive and have a long lead time to start producing. As such, the decision to invest in a new venture or plant depends on the expectation on the behavior of prices for several years ahead. Consumers would benefit from predicting the short and medium term prices to better manage their inventories and working capital while investors may decide to take exposure to the prices of commodities for a number of reasons, such as reducing systematic risk, or simply for speculative purposes.

Since commodities markets are cyclical and very volatile, the good understanding of its variability offers an important competitive advantage to producers, consumers and investors. To better manage their exposure to commodities fluctuations, these players use to hedge some of their positions using conventional techniques. As described by Ripple and Moosa (2007), convenience yield plays an important role in the implementation of hedging strategies.

The term structure of commodities prices also plays an important role on the products supply and demand. Since it incorporates the risk-neutral future price expectation, producers make decisions about the amount to offer at any period of time, while consumers can decide to anticipate or delay the purchase of raw materials or even hedge their exposure.

Convenience yield is a central component for the shape of commodities futures prices. Fundamentals described by the theory of storage are commonly applied to measure the occurrence and dimension of this yield. This way, if hedging or investment strategies are based upon the standard theory, any decoupling between those predictions and the real behavior of this component could result in material losses to the industry and capital markets. As such, the motivation of this study relies on the importance of a better understanding on the behavior on commodity prices and, more specifically, on the relationship between inventories and the volatilities observed in the prices of future and forward contracts. Since future and forward contracts are among the most widely used hedging instruments, it is highly relevant to empirically test the implications yielded by the extant theoretical framework on the subject.

This study extends the methodology developed by Fama and French (1988) to test the existence and impacts of convenience yield in the future prices and volatilities of storable commodities. Based on the theory of storage proposition that the marginal convenience yield decreases at a decreasing rate as inventory rises (Samuelson, 1965), I test this hypothesis by examining the relative variation of spot and futures prices for West Texas Intermediate (WTI) crude oil, aluminum and copper.

Fama and French's (1988) results are extended by the inclusion of the WTI crude oil in our tests. Petroleum is perhaps the most important commodity today and its price directly affects several industries somehow related to energy, transportation and manufacturing as well as the economies of many nations that rely on hydrocarbon production as their most relevant source of revenues. In this sense, the addition of this particular commodity to Fama and French's results is one of the main contributions of this study.

I also extend Fama and French's analysis, by repeating their tests for aluminum and copper, but using a longer sample that contains the 2005-2007 commodities bubble and the late 2008 market collapse. I consider this to be especially important since financial markets have suffered significant changes both in terms of volume traded and number of players, as well as in the sophistication of models used by hedgers and traders. More specifically, in the 2005-2008 period, market participants faced tremendous challenges due to the huge spike and subsequent decline on commodity prices, a phenomenon never before observed.

In a nutshell, the results found for the price of the base metals are, in general, consistent with the Theory of storage. However, I find mixed evidence on the price of WTI, since not all of the implications of the Theory of storage are empirically verified.

The remainder of this study is organized as follows: the second chapter describes the extant literature concerning the theory of storage and its implications on the prices of commodities, the third chapter is dedicated to the description of the commodities and the types of contracts traded at different exchanges, the fourth chapter discusses the model used, the fifth chapter describes the data used in this study, the sixth chapter presents the results obtained and the seventh chapter concludes.

2 THE THEORY OF STORAGE AND THE VOLATILITY OF COMMODITY PRICES

During any period there will be firms carrying stocks of a commodity from a period into the next. Brennan (1958) defines a supplier of storage as anyone who holds title to stocks with a view to their future sale, either in their present or in a modified form. On the other hand, demanders of storage are those groups who want to have stocks carried for them from one period to another.

The equilibrium between supply and demand of storage will happen when the marginal revenue of stocks carried out of period *t* equals the net marginal cost of storage where the marginal revenue is defined as the expected change in price prom period *t* to *t+1*. Therefore, the equilibrium can be written as follows:

$$o_t'(S_t) + r_t'(S_t) - c_t'(S_t) = EP_{t+1} - P_t \qquad (1)$$

Where $o_t(S_t)$ is the total outlay on physical storage (storage, handling costs and interest on inventories held), $r_t(S_t)$ is the total risk-aversion factor and $c_t(S_t)$ the total convenience yield.

Consistent with the theory of storage, Samuelson (1965) predicts that spot and futures price variations will be similar when a supply or demand shock occurs during periods with higher inventory levels, but spot prices will be more variable than the futures prices when inventory levels are low. He also concludes that the future or forward contracts will show lower volatility for longer than for shorter maturities, since suppliers take some time to respond to a demand shock by increasing or decreasing their output production. The same happens to consumers, that may not be able to alter their input in the short run, but may be able to do so in the longer run.

Thus, one can understand that the variation of futures prices is a decreasing function of maturity. This happens because the supply of storage, as defined by Brennan (1958), can minimize or even neutralize the impact of a supply/demand shock and a high inventory level implies a lower probability of a stock-out in the future.

Building on Samuelson's and Brennan's ideas, Fama and French (1988) describe the forward (or futures) price at time *t* for a commodity to be delivered at *T*, F(*t*,T) as follows:

$$F(t,T) - S(t) = S(t)R(t,T) + W(t,T) - C(t,T) \qquad (2)$$

where, *S(t)* is the spot price in instant *t*, *F(t,T)* is the price in *t* on the future with maturity in *T*, *W(t,T)* is the total warehouse cost from period *t* to *T* and *C(t,T)* is the convenience yield from *t* to *T,* and *R(t,T) is the interest rate from t to T.*

The rationale for the relationship shown in equation (1) derives from the theory of storage, which says that the return from purchasing the commodity at *t* and selling it at *T*, *F(t,T) – S(t)*, equals the interest foregone during storage *S(t)R(t,T)*, plus the marginal warehousing cost, W(*t*,*T*), minus the marginal convenience yield C(*t*,*T*).

When inventory level is high, the marginal convenience yield tends to zero, and future prices are higher than spot prices, putting the term structure of the commodity curve in a typical contango shape. When inventories are low, convenience yield is high and the forward curve stays in backwardation. In this case, there is a premium from selling the physical commodity and purchasing the future. In this case, it is said that the owners of the commodity have incentive to destocking (selling the spot). The equilibrium occurs when the players destock until a level that the convenience yield on the remaining stockpile (which increases as inventory decreases) is greater than the benefit from selling the spot and buying the forward.

As Pindyck (2001) describes, extractive resources are expected to trade in backwardation most of the time. The reason is that the proprietary of the reserve owns a call option that can be exercised at any period of time (extract and sell the product). To decide whether to extract now or in the future, one of the decision factors is the futures prices curve. That said, the term structure of the commodity price should give to the producer an incentive to produce more (i.e. higher short-term prices than long-term prices), specially when inventories are low.

Inventory level, and consequently prices, can be affected by supply/demand shocks and seasonality. Industrial metals are not much affected by seasonality, but production disruptions

are frequent, mainly because of strikes and mine closures. Inventories of these materials are more influenced by business cycles and economic conditions.

For the crude oil and agricultural commodities market, seasonality is an important factor. In the case of crude oil, more heating oil is consumed in the winter while in the summer people use it to drive more (the so called driving season), elevating gasoline consumption and affecting oil's convenience yield. As noted by Fama and French (1988), for agricultural commodities, the seasonality of harvests affect directly the level of inventories which tend to be low before the crops, implying in an elevated convenience yield, putting the forward prices curve in backwardation.

The existence of convenience yield can be explained as the uncompensated benefit of holding the physical commodity, which arises mostly from operational reasons like reducing lead times, avoiding production cuts and assuring stable outflow. Those kinds of benefits have returns that are immensurable at first look, for example, if a blast furnace runs out of raw materials and must be turned off, the steelmaker will incur in several costs to rebuild its refractory so they have to keep a minimum level of physical inventory to avoid this kind of risk.

As an implication of the theory of storage, Samuelson (1965) points that with high inventory levels, spot and futures prices variations will be similar when a supply/demand shock occurs, but spot prices will vary more then futures at lower inventory levels. Fama and French (1988) tested the theory of storage, based on the hypothesis that the marginal convenience yield declines at higher inventory levels but at a decreasing rate. Rather than test the hypothesis by examining the direct relation between convenience yield and inventories, they test its implications as described by Samuelson's proposition.

The authors tested the theory of storage prediction that future prices are less variable than spot prices when inventory is low (the Samuelson hypothesis) but spot and futures prices have roughly the same variability. Using a proxy for the inventory level, their tests for industrial metals aluminum, copper, lead, tin and zinc supported a refinement of the Samuelson proposition. I return to Fama and French's (1988) methodology in detail on section 4 ahead.

3 CHARACTERISTICS OF THE STUDIED COMMODITIES

3.1 Crude Oil

Crude oil is the most traded commodity, traditionally traded by means of futures contracts. Those contracts are mostly traded in the New York Mercantile Exchange (NYMEX)[1] and London's Intercontinental Exchange (ICE). According to the NYMEX and ICE websites, there were more than 4.0 million future contracts of petroleum with open interest as of year end 2008. Each contract refers to 1,000 barrels of oil, so the open interest, just on NYMEX, and ICE corresponds to over a 4 billion barrels of oil, which is roughly equivalent to 2 months of the world's production today. The benchmark crude oil traded in NYMEX is the West Texas Intermediate (WTI), while ICE contracts are based on the North Sea Brent Blend crude oil (or simply, Brent). The contracts traded in these two markets are based on crude oil from different production areas and consequently with different physical and chemical characteristics (viscosity, density, sulphur content etc). The spot prices from the North American and West African oil fields are quoted based on the value of WTI crude oil, while the Brent is used as a benchmark for the petroleum produced in the North Sea, Russia, Middle East and Northern Africa.

The crude oil market is subject to a seasonal cycle of supply and demand, with price adjusting to supply/demand disequilibrium. Beside the seasonal factors, geopolitical issues use to play an important role on the supply side, causing uncertainties and sometimes increasing oil's convenience yield

Figure 1 shows us the historical prices for WTI and Brent January 1990 to December 2008, and table 1 illustrates the annual average spot prices, rates of return and volatilities for both types of oil.

[1] Specifications and description of the contracts may be found at http://www.nymex.com/WS_desc.aspx for the WTI crude oil and at https://www.theice.com/productguide/ProductDetails.shtml?specId=219 for the Brent.

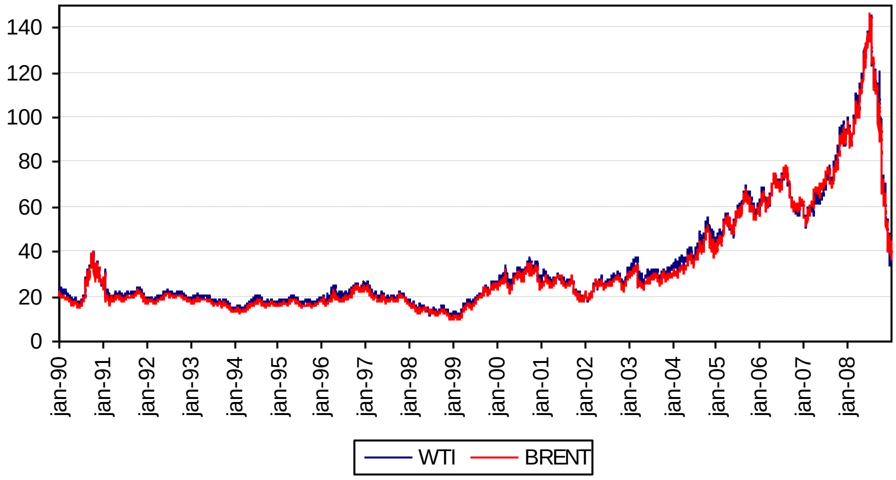


Figure 1. WTI and Brent historical prices

This figure shows the nominal spot prices for the West Texas Intermediate (WTI, blue line) and Brent (red line) oils for the period 1990-2008 in US Dollars per barrel. It shows that the price has stayed suffered a spike during the first Gulf War in late 1990, and then remained quite stable around USD20/bbl until 2003. From 2004 on, prices have experienced a sharp rise, reaching almost 150 USD/bbl in early 2008, collapsing to less than one-third of this value a few months later.

3.2 Copper

Copper futures are mostly traded in the London Mercantile Exchange (LME), in the New York Commodity Exchange (COMEX), a division of NYMEX and in the Shanghai Futures Exchange (SFE). It is the most traded of the industrial as of year end 2008, there were circa 15 thousand contracts with open interest at the LME, each contract accounting for 25 tons, resulting in over 7 billion tons with open interest, which corresponds to nearly half of the yearly overall production). In the LME, copper is traded in forward contracts and the three month contract is the most liquid. In COMEX and SFE, trading happens in future contracts, with monthly maturities.

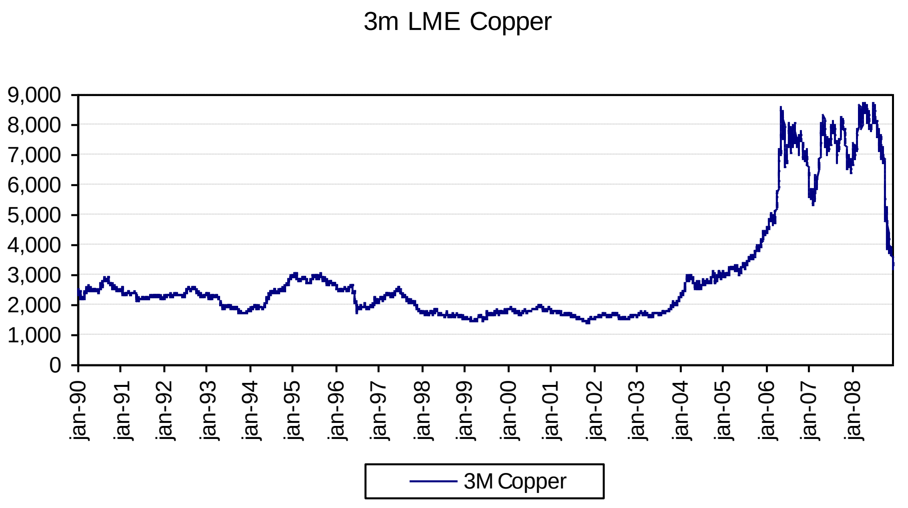


Figure 2. Three months forward LME copper historical prices

This figure shows the nominal 3 months forward LME copper prices for the period 1990-2008 in US Dollars per metric ton. The 3 months contracts are the better proxy for prices once they are the most traded ones. It shows that the price has suffered two spikes in late 1990 and in 1995, and then remained quite stable around USD2.000/t until 2003. From 2004 on, prices have experienced a sharp rise, reaching almost 9.000 USD/t in early 2008, collapsing to less than one-half of this value a few months later.

3.3 Aluminum

Aluminum is one of the most important materials, linked to industry growth. This metal is intensively used in industrial machines, automobiles and airplanes parts and on a broad kind of packages. It is the second most traded base metal, generally negotiated in a high grade quality contract. Like copper, aluminum is traded in the LME, as forward contracts and in the SFE in futures form.

Below, figure 3 shows the historical price for the 3 months forward LME aluminum contract:

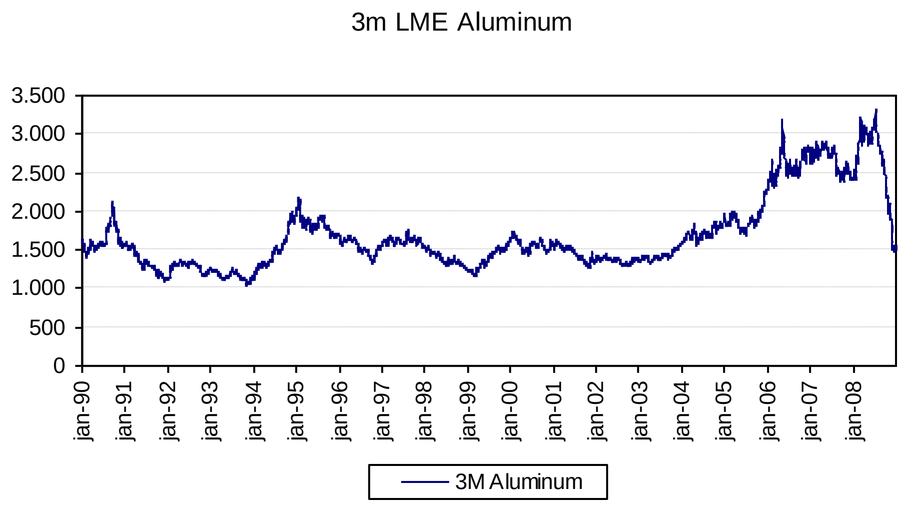


Figure 3. Three months forward LME aluminum historical prices

This figure shows the nominal 3 months forward LME aluminum prices for the period 1990-2008 in US Dollars per metric ton. The 3 months contracts are the better proxy for prices once they are the most traded ones. It shows that the price has suffered two spikes in late 1990 and in 1995, and then remained quite stable around USD1.500/t until 2003. From 2004 on, prices have experienced a sharp rise, reaching almost 3.500 USD/t in early 2008, collapsing to less than one-half of this value a few months later.

4 THE MODEL

Measuring inventories for commodities that are internationally traded is a difficult task that may be dealt by different approaches and is subject to many sources of uncertainty. Copper, aluminum and crude oil are widely traded in the seaborne market, so there is always lot of product in transit in ships. In the specific case of petroleum, oil in pipelines is also an important source of stocks. Inventory of oil-derived fuels is also relevant to the formation of oil prices, since both consumers and retailers usually have inventories of their own. Additionally, some governments have strategic reserves of commodities.

Those issues make the accuracy of data on short-term variation in aggregate inventory questionable. Despite those issues, some authors used real inventory data like the weekly report on crude oil inventories from de United States Department of Energy (DOE), the daily LME inventory data for base metals or other data from specialized researches.

As described in section 2, convenience yield can be described as the uncompensated benefit of holding the physical commodity. As such, since my study has the convenience yield as a central idea, in this study, I consider as inventory all the products available in the supply chain that could provide this uncompensated benefit. Not only commodities available in warehouses provide this yield. For instance, if a wire producer has a copper inventory in transit (and if he trusts the supplier), he can run his production with a low level of inventory in his plant, counting on the future inflow and benefiting for the convenience yield of this product in transit.

For this reason, instead of testing directly the hypotheses about inventory and the variation of spot and forward prices, I use Fama and French’s (1988) proposition, using the “interest-adjusted basis” as a proxy for low or high inventory level. This approach is the central idea of the model that drives this study.

4.1 The relation between Forward and Spot prices: Theory

As it is shown in equation (2), the theory of storage predicts that the return from purchasing the commodity at t and selling it at a future date T, $F(t,T) - S(t)$, equals the interest foregone

during storage S(t)R(t,T), plus the marginal warehousing cost, W(t,T), minus the marginal convenience yield C(t,T), i.e.:

$$F(t,T) - S(t) = S(t)R(t,T) + W(t,T) - C(t,T)$$

The storage equation (2) implies that the difference between the basis, [F(t,T) – S(t)]/ S(t), and the interest rate, R(t,T), is:

$$[F(t,T) - S(t)]/ S(t) - R(t,T) = [W(t,T) - C(t,T)]/ S(t) \qquad (3)$$

F(t,T), S(t) and R(t,T) are observable. Thus, the observed result on the left-hand side of (3) is the interest-adjusted basis, and corresponds to the yield provided to the player that carries the commodity from the instant t to T, or the yield paid for the player that needs the product in instant t and cannot afford to wait until T. This value equals the difference between the relative warehousing cost, $w(t,T)$ = W(t,T)/S(t) and the relative convenience yield, $c(t,T)$ = C(t,T)/S(t). This observation is used for developing the testable hypothesis about the relation between convenience yield and the relative variation of spot and futures prices.

According to the 2007 EIA annual report, the storage cost of crude oil is approximately 30 cents per barrel/month. The rates for copper are on average 35 cents per ton in LME warehouses. This accounts for about 0.50% of the crude oil spot price and less than 0,01% of copper spot prices. That said, it is assumed, virtually without loss of information, that marginal warehousing costs for metals are roughly constant over the relevant range of inventory, and variation in C(t,T) dominates variation in W(t,T).

The theory of storage predicts that the relative convenience yield $c(t,T)$ falls with increases in inventory, but at a decreasing rate; $\partial c/\partial I < 0$ and $\partial^2 c/\partial I^2 > 0$. The marginal benefit of holding one more unit of the commodity is a decreasing function of the inventory level since the importance of the new unit gets smaller while the socks increase. Figure 4 shows the convenience yield and the interest-adjusted basis function relative to the inventory level. At low levels, the convenience yield c(t,T) is larger then the warehousing cost $w(t,T)$, and the interest-adjusted basis is negative. At higher inventory levels, $c(t,T)$ falls toward 0; the interest-adjusted basis becomes positive and rises toward $w(t,T)$.

The assumption of Figure 4 that the marginal convenience yield declines with increases in inventory at a decreasing rate allows us to make predictions about the impact of demand and supply shocks on spot and forward prices.

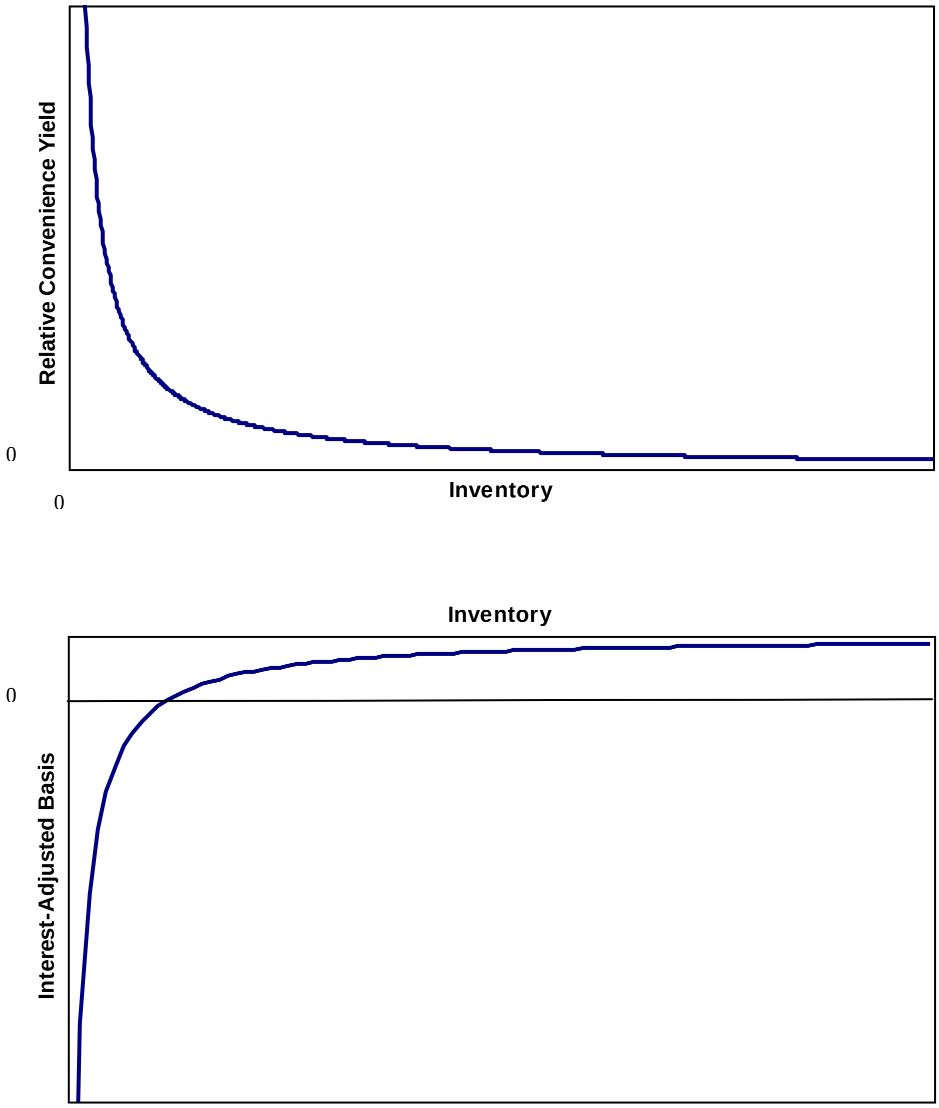


Figure 4. The Relative Convenience Yield and the Interest-Adjusted Basis as Functions of Inventory. Adapted from Fama and French (1988)

This figure shows that the lower are the inventories, the higher is the convenience yield of holding a certain commodity. Moreover, marginal utility diminishes at a decreasing rate as inventory increases. Therefore, from equation 3, assuming that warehousing costs are constant, the interest adjusted basis may be used a proxy for high or low inventory.

For example, suppose there is a permanent positive shock in the demand of crude oil. Prices (spot and futures) would immediately get higher and demand for gasoline, diesel and other derivates would decrease. Also, because of the higher prices, many producers would have incentive to invest in new extraction capacity to ramp up their production. These demand and

supply responses partly offset the effect of the shock on expected prices. Although the demand shock is permanent, the impact in current spot prices is more relevant than in expected spot prices since anticipated supply and demand responses are expected to be able to restore the supply-demand equilibrium.

While the disequilibrium persists (i.e., demanded quantity > supplied quantity), inventory will be consumed and convenience yield will increase. This way, we can say that the relative effect of the permanent demand shock on current and expected spot prices also depends on inventory level and the shape of convenience yield function. At high inventory levels, convenience yield function is almost flat. There can be a large supply of storage to reach the new demanded quantity without a large change in the convenience yield or the interest-adjusted basis. The inventory response minimizes the effect of the shock in current spot prices making its variation not so different than expected forward prices changes.

In contrast, at low inventory levels, the supply of storage is more limited and expected inventory response is smaller, increasing the probability of a stock-out. As a consequence, the convenience yield rises faster while inventory is consumed to meet an increase in demand, causing spot prices to vary more then futures prices. The change in expected spot prices is smaller because the market anticipates future demand and supply responses to reinstate market equilibrium.

Since the measurement of total inventory levels is an imprecise data, Fama and French (1988) used the interest adjusted basis as a proxy for inventory level. When inventory is high, the marginal convenience yield on inventory is low and the interest adjusted basis is positive. On the other hand, when inventory is low, the convenience yield is low and the interest adjusted basis is negative. Thus I define as low inventories periods those when de interest adjusted basis is negative and as high inventories periods those with positive interest adjusted basis.

Ng and Pirrong (1994) extended Fama and French (1988) results employing a bivariate dynamic model that allows past spreads to affect both the volatility of spot and forward returns and the correlation between them. The authors estimated the model using data on spot and forward prices for industrial metals traded on the LME and for Silver.

Consistent with the predictions of the Theory of Storage, the model found that the lagged-squared-adjusted spread has a statistically significant effect on the variances of both spot and forward returns and on the correlation between this returns, confirming the implications of the theory.

4.2 Previous results

As the dominant model of commodities futures prices, the theory of storage is a well known and tested model. Fama and French (1987, 1988), Ng and Pirrong (1994) and Duan and Lin (2007) developed statistical models to test empirically the implications of the theory. The studies are described in detail below.

Fama and French (1987) made a regression on the basis $[F(t,T) - S(t)]/ S(t)$ against the nominal interest rate $R(t,T)$ and monthly seasonal dummies:

$$[F(t,T) - S(t)]/ S(t) = \sum a_m d_m + \beta R(t,T) + e(t,T)$$

Where d_m equals 1.0 if the futures contracts matures in month m and 0.0 otherwise. According to the hypothesis of the storage equation (2), the slope β should be 1.0 for any continuously stored commodity.

The sample included agricultural commodities, metals, animal and wood products for a period between January 1967 and May 1984. Metals produced the strongest evidence of variation the basis that tracks interest rates, with gold pointing the strongest results among the metals with coefficients ranging from 0.99 to 1.07 on the 1, 3, 6 and 12 months to maturity forward contracts.

The regressions for the agricultural and wood products were also consistent with the hypothesis that basis varies one for one with the nominal interest rates (coefficients positive, and mostly less than 1.0 standard deviation form 1.0) while the coefficients for the animal products were less precise.

Extending their results, Fama and French (1988) developed an alternative methodology to test the Theory of Storage. The authors used the interest-adjusted basis $[F(t,T) - S(t)]/ S(t) - R(t,T)$ as a proxy for high (positive basis) and low (negative) inventories and tested the hypothesis

that futures prices are less variable than spot prices when inventory is low, but spot and futures prices have similar variability when inventory is high. They also tested de Samuelson´s proposition that variation of futures prices is a decreasing function of maturity.

Fama and French’s tests included daily observations from the LME industrial metals and silver, and also data from New York Commodity Exchange (COMEX) for copper and gold for a period between 1972 and 1983.

Results pointed that the interest-adjusted basis is more variable when it is negative (low inventories), with the standard deviations of the basis for aluminum, copper, lead, tin and zinc being at least forty-five percent larger when it is negative then when it is positive. F-tests for the industrial metals reject the hypothesis that the variance of the interest-adjusted basis does not depend on its sign at the 0.955 probability level.

Ng and Pirrong (1994) applied a bivariate dynamic model where they analyzed the effect of past spreads in the volatility of spot and forward returns and in the correlation between them. The sample included data form the 1986 – 1992 period for four industrial metals, aluminum, copper, lead and zinc and for a precious metal, silver. The results for the industrial metals are consistent with the predictions of the theory of storage. The lagged-squared-adjusted spread has a statistically significant effect on the variances of both spot and forward returns and for the correlation between them, explaining between 50% and 70% of the spot returns variances and 50% to 62% of the forward-return variances.

Duan and Lin (2007) used option approach of Heinkel et al. (1990) with the Black-Scholes model to estimate convenience yield ant test the theory of storage proposition that the marginal convenience yield on inventory falls at a decreasing rate as inventory increase. Their obtained results were consistent with Fama and French (1988) in that commodity prices are more volatile than futures prices at low inventory level, and also confirmed the Samuelson’s hypothesis that variability of futures prices is an inverse function of the maturity.

In order to apply the fundamentals of the theory of storage, Braham et al. (2006) used the convenience yield to explain the variation in spread between oil and its derivates. Ripple and Moosa (2007) calculated the hedge ratios for the NYMEX crude oil to examine the relation between hedge effectiveness and the maturity of the futures contracts.

Bahram et al (2006) employed the convenience yield implicit in the term structure of gasoline and heating oil prices as a proxy to explain the spread between the prices of crude oil and those derivates. The authors proposed that under uncertainty, spreads between crude oil and refined products will arise not only from refining and warehousing costs, but also from the expectation of the future relative supply and demand that are implied in the convenience yield contained in the term structure of gasoline, heating oil and crude oil.

To analyze the impact of convenience yields on the petroleum spreads, the authors performed a multiple linear regression with OLS estimators putting the prices spread as endogenous variables and the convenience yields spread as exogenous variables, as follows:

$$\ln F^{G}_{t}(m) - \ln F^{C}_{t}(m) = a + b(y^{G}_{1,12,t} - y^{C}_{1,12,t}) + e_{t} \qquad (4)$$

Where F^{G}_{t} and F^{C}_{t} are the gasoline and crude oil future prices in instant t respectively, and $y^{G}_{1,12,t}$ and $y^{C}_{1,12,t}$ are the gasoline and crude oil convenience yields implicit in the 12 months future contracts respectively.

In addition, the study introduces the marginal convenience yield to proxy futures term structure with the intention to achieve better explanatory power. This way, the authors performed another multiple regression with disaggregated convenience yield:

$$\ln F^{G}_{t}(m) - \ln F^{C}_{t}(m) = a + \beta_{1}(y^{G}_{1,12,t} - y^{C}_{1,12,t}) + \ldots + \beta_{6}(y^{G}_{6,12,t} - y^{C}_{6,12,t}) + e_{t} \qquad (5)$$

Encountered results showed that the difference in convenience yields explains the majority of the behavior in spreads. The adjusted R^2 for the aggregate yield differentials (equation 4) was 0,72 for the gasoline-crude spread and 0,55 for the heating oil-crude spread. The tests also concluded that there are benefits in disaggregating the yields by contract maturity (equation 5) where the explanatory power (adjusted R^2) have risen to 0,79 and 0,76 for gasoline-crude spread and heating oil-crude spread respectively.

The convenience yield also plays an important role in hedge effectiveness. Ripple and Moosa (2007) calculated the hedge effectiveness to a portfolio with WTI crude oil exposure. The authors used the NYMEX crude oil spot and futures contracts to calculate the hedge ratios and

the measures of hedging effectiveness resulting from the use of the near-month contract and those resulting from the use of a 6 months contract.

The hedge ratios were calculated as the slope coefficient in a regression of the rate of return on the spot prices on the rate of return on the futures prices (hedging instrument). Let S_t and F_t be the logarithms of the spot and futures prices respectively, then the hedge ratio h is measured as follows:

$$\Delta S_t = \alpha + h\Delta F_t + e_t \qquad (6)$$

The authors found that hedge ratios are lower for near-month hedging than for 6-month hedging, and that hedging effectiveness seems to be higher across the board when 6 months contracts are used.

The first observation is in accordance with Samuelson's (1965) proposition that variability of commodities contracts is an inverse function of its maturity. The second one leads us to believe that volatilities behavior are different along the commodities forward curve and in the case of WTI, near contracts vary closer to the spot contracts then the far ones.

5 DATA

The data includes daily observations from the London Metals Exchange (LME) on spot, three-month and fifteen-month forward prices for copper. I examine prices from January 1990 to December 2008. I also included the 6 months forward contract for both metals from July 1997 to December 2008, once the availability of this data is more restricted. The tests that include the three maturities (3 months, 6 months and 15 months) contemplate only the shorter period. The LME data has the advantage of having simultaneous spot and forward prices, for fixed forward maturities, every business day.

For the WTI crude oil, I use daily observations from the New York Mercantile Exchange (NYMEX) on the first, fourth and sixteenth months for the period beween January 1990 to 2008 and for the seventh month futures from July 1997 to December 2008 to better compare the three commodities. Since the WTI contract doesn't have a fixed maturity, we used the first contract as a proxy for the spot, and the fourth, seventh and sixteenth futures as proxies for three, six and fifteen months forward respectively.

6 RESULTS

6.1 The Variability of the Interest-Adjusted Basis

In order to test the prediction of the theory of storage that the supply/demand shocks produce more variability in spot prices than in forward prices when inventories are low but have roughly the same impact in forward and spot prices when inventories are high, I tested whether the interest-adjusted basis is more variable when it is negative.

Table 1 shows the average of daily values of the interest-adjusted basis and the standard deviations of the daily changes of the interest-adjusted basis. Results for aluminum and 15 months copper brought evidence that the variability of the interest-adjusted basis is larger when it is negative than when it is positive. For the 3 months forward copper and both crude oil maturities, the results are consistent with that prediction F- tests (Table 2) did not rejected the hypothesis that the interest adjusted basis variability does not depend on its signal at the 0.99 probability level for the 3 months forward contracts of copper and aluminum. All the other tests rejected that hypothesis that is not in accordance with the theory of storage.

Table 1. Average of Daily Values of the Interest-Adjusted Basis and Standard Deviations of Daily Changes in the Interest-Adjusted Basis

This table shows the average of daily values of the interest-adjusted basis and the standard deviations of daily changes in the interest-adjusted basis from 1990 to 2008, providing data for both commodities in all sample, only positive and only negative interest-adjusted basis subsamples.

		average			standard deviation		
		positive	negative	all	positive	negative	all
Aluminum	3 Mo Fwd	0.87	-1.32	0.12	0.12	0.34	0.24
Aluminum	15 Mo Fwd	5.27	-1.97	-3.24	0.33	0.57	0.53
Copper	3 Mo Fwd	3.55	-2.88	-0.65	0.83	0.78	0.91
Copper	15 Mo Fwd	2.08	-12.40	-8.77	0.52	0.91	0.92
WTI	4 Mo Fut	3.09	-4.71	-1.88	1.28	1.00	1.13
WTI	16 Mo Fut	8.36	-14.26	-9.88	2.41	1.35	1.62

Table 2. F-tests for Equality of Variances.

This table presents f-tests for equality of variances between the interest-adjusted basis on the subsamples that include only positive and only negative values of the interest-adjusted basis. F-stat is the ratio between the variance of the negative subsample to the positive ones.

H_0
var(positive)=var(negative)

Copper (3M)

F-Tests	
Var (All)	15.19
Var (Positive)	5.57
Var (Negative)	5.94
F-stat	
Ratio	1.07

F-critical	
Probability	0.990
inferior	superior
0.89	1.13

Hypothesis
Not rejected

Copper (15M)

F-Tests	
Var (All)	80.61
Var (Positive)	1.48
Var (Negative)	54.50
F-stat	
Ratio	36.84

F-critical	
Probability	0.990
inferior	Superior
0.88	1.14

Hypothesis
Rejected

Aluminum (3M)

F-Tests	
Var (All)	1.95
Var (Positive)	5.57
Var (Negative)	5.94
F-stat	
Negative	1.07

F-critical	
Probability	0.990
inferior	superior
0.90	1.12

Hypothesis
Not rejected

Aluminum (15M)

F-Tests	
Var (All)	35.11
Var (Positive)	6.00
Var (Negative)	19.73
F-stat	
Negative	3.29

F-critical	
Probability	0.990
inferior	Superior
0.90	1.12

Hypothesis
Rejected

Oil (3M)

F-Tests	
Var (All)	26.38
Var (Positive)	10.10
Var (Negative)	13.53
F-stat	
Ratio	1.34

F-critical	
Probability	0.990
inferior	superior

Oil (15M)

F-Tests	
Var (All)	160.44
Var (Positive)	68.40
Var (Negative)	83.58
F-stat	
Ratio	1.22

F-critical	
Probability	0.990
inferior	Superior

0.90	1.13
Hypothesis	
Rejected	

0.87	1.15
Hypothesis	
Rejected	

Tables 3 and 4 includes the 6 months forward contracts, repeating the calculus presented in Tables 1 and 2. In table 3, we can note that again, Aluminum is in accordance with the prediction that the interest adjusted basis is more variable when it is positive. 6 and 15 months forward contracts also corroborate the prediction, while 3 months copper and all the WTI maturities did not provide any evidence on that.

Table 3. Average of Daily Values of the Interest-Adjusted Basis and Standard Deviations of Daily Changes in the Interest-Adjusted Basis July 1997 – December 2008

This table shows the average of daily values of the interest-adjusted basis and the standard deviations of daily changes in the interest-adjusted basis from July 1997 to December 2008, providing data for both commodities in all sample, only positive and only negative interest-adjusted basis subsamples.

		average			standard deviation		
		positive	negative	all	Positive	negative	all
Aluminum	3 Mo Fwd	0.79	-1.11	0.09	0.11	0.36	0.24
Aluminum	6 Mo Fwd	1.64	-1.76	-0.39	0.21	0.46	0.32
Aluminum	15 Mo Fwd	5.84	-2.02	-3.58	0.35	0.59	0.55
Copper	3 Mo Fwd	3.05	-2.21	0.03	0.78	0.24	0.57
Copper	6 Mo Fwd	1.50	-5.18	-2.60	0.48	1.30	1.07
Copper	15 Mo Fwd	2.07	-10.92	-5.82	0.32	0.57	0.46
WTI	4 Mo Fut	2.97	-4.85	-1.06	1.24	1.11	1.11
WTI	7 Mo Fut	5.10	-7.79	-2.95	1.72	0.99	1.32
WTI	16 Mo Fut	9.21	-14.36	-8.83	2.63	1.19	1.65

Table 4 repeats the F-tests presented in table 2 for the new sample. Only for the 3 months forward copper we did not reject the hypothesis that the variability of the interest-adjusted basis does not depend on its signal. All the other contracts are in accordance with the theory (the variability of the interest-adjusted basis depend on its signal).

Table 4. F-tests for Equality of Variances (1997 – 2008).

This table presents f-tests for equality of variances between the interest-adjusted basis on the subsamples that include only positive and only negative values of the interest-adjusted basis. F-stat is the ratio between the variance of the negative subsample to the positive ones.

H_0
var(positive)=var(negative)

Copper (3M)

F-Tests	
Var (All)	11.02
Var (Positive)	5.33
Var (Negative)	3.45
F-stat	
Negative	0.65

F-critical	
Probability	0.990
inferior	superior
0.90	1.12

Hypothesis
Not rejected

Copper (6M)

F-Tests	
Var (All)	22.81
Var (Positive)	1.18
Var (Negative)	19.17
F-stat	
Negative	16.22

F-critical	
Probability	0.990
inferior	superior
0.90	1.12

Hypothesis
Rejected

Copper (15M)

F-Tests	
Var (All)	69.52
Var (Positive)	1.29
Var (Negative)	48.88
F-stat	
Negative	37.84

F-critical	
Probability	0.995
inferior	superior
0.88	1.14

Hypothesis
Rejected

Aluminum (3M)

F-Tests	
Var (All)	1.52
Var (Positive)	0.28
Var (Negative)	1.38
F-stat	
Negative	4.85

F-critical	
Probability	0.990
inferior	superior
0.90	1.12

Hypothesis
Rejected

Aluminum (6M)

F-Tests	
Var (All)	4.60
Var (Positive)	1.13
Var (Negative)	2.30
F-stat	
Negative	2.04

F-critical	
Probability	0.990
inferior	superior
0.90	1.12

Hypothesis
Rejected

Aluminum (15M)

F-Tests	
Var (All)	29.62
Var (Positive)	4.84
Var (Negative)	15.72
F-stat	
Negative	3.25

F-critical	
Probability	0.990
inferior	superior
0.89	1.13

Hypothesis
Rejected

Oil (3M)

F-Tests	
Var (All)	25.17
Var (Positive)	9.08
Var (Negative)	15.97
F-stat	
Negative	1.76

F-critical	
Probability	0.995

Oil (6M)

F-Tests	
Var (All)	64.90
Var (Positive)	27.05
Var (Negative)	25.28
F-stat	
Negative	0.93

F-critical	
Probability	0.995

Oil (15M)

F-Tests	
Var (All)	183.52
Var (Positive)	83.49
Var (Negative)	83.86
F-stat	
Negative	1.00

F-critical	
Probability	0.995

inferior	superior
0.90	1.13

Hypothesis
Rejected

inferior	superior
0.87	1.15

Hypothesis
Rejected

inferior	superior
0.87	1.15

Hypothesis
Rejected

To test whether the commodities bubble influenced the results, I performed the same tests excluding the period between 2005 and 2008 for the sample. Results shown in Table 5 do not indicate any significant change to the whole sample conclusions.

Table 5. Average of Daily Values of the Interest-Adjusted Basis and Standard Deviations of Daily Changes in the Interest-Adjusted Basis – 1990-2004

This table shows the average of daily values of the interest-adjusted basis and the standard deviations of daily changes in the interest-adjusted basis from 1990 to 2004, providing data for both commodities in all sample, only positive and only negative interest-adjusted basis subsamples.

		average			standard deviation		
		positive	negative	all	positive	negative	all
Copper	3 Mo Fwd	3.57	-2.91	-0.16	0.84	0.92	1.01
Copper	15 Mo Fwd	2.03	-11.50	-7.35	0.51	1.03	1.01
WTI	4 Mo Fut	3.12	-4.99	-2.79	1.33	1.01	1.14
WTI	16 Mo Fut	8.72	-16.07	-12.19	2.35	1.42	1.61

Since Fama and French's threshold on the interest adjusted basis to define high and low inventories (positive and negative interest-adjusted basis) is quite arbitrary, I use the median of the interested adjusted basis as a threshold to split the sample into high and low inventories. Thus, I consider that observations for which the interest adjusted basis is above the median as high inventories and observations for which the interest adjusted basis is below the median as low inventories. Results in table 6 show that the variability of the interest-adjusted basis for both commodities and maturities converged, and F-tests (not reported) did not rejected the hypothesis that variance of the interest-adjusted basis does not depend on whether it is above or below its median at the 0.995 probability level, except for the 15 months copper .

Table 6. Average of Daily Values of the Interest-Adjusted Basis and Standard Deviations of Daily Changes in the Interest-Adjusted Basis

This table shows the average of daily values of the interest-adjusted basis and the standard deviations of daily changes in the interest-adjusted basis from 1990 to 2008, providing data for both commodities in all sample, above median and under median interest-adjusted basis subsamples.

		average			standard deviation		
		Above median	below median	all	Above median	below median	all
Copper	3 Mo Fwd	2.33	-3.63	-0.65	0.85	0.87	0.91
Copper	15 Mo Fwd	-1.16	-16.39	-8.77	0.84	0.96	0.92
WTI	4 Mo Fut	2.01	-5.77	-1.88	1.13	1.08	1.13
WTI	16 Mo Fut	-0.17	-19.61	-9.88	1.70	1.46	1.62

6.2 The relative Variability of Spot and Forward Prices

The shape of the convenience-yield function in Figure 2 implies that supply/demand shocks produce roughly equal changes in spot and forward prices when inventory is high but spot prices vary more then forward prices when inventories are low.

To test this prediction, I calculated the ratio of the standard deviation of daily percent changes on forward prices to the standard deviation of daily percent changes on spot prices, for both positive and negative interest adjusted basis.

Results in Table 7 are consistent with the prediction, showing that the ratio is close to 1.00 when the interest-adjusted basis is positive, but ratios are lower (forward prices are less variable then spot prices) when the interest-adjusted basis is negative.

Table 7. Ratios of the Standard Deviation of Daily Forward (or Futures) Price Changes to the Standard Deviation of Daily Spot Price Changes

This table shows the ratios of the standard deviation of daily forward (or futures) price changes to the standard deviation of daily spot price changes providing data for both commodities in all sample, only positive and only negative interest-adjusted basis subsamples.

	Standard Deviation Ratios		
	Positive	**Negative**	**All**
copper 3M	0.995	0.867	0.892
copper 15M	0.968	0.808	0.831

	Standard Deviation Ratios		
	Positive	**Negative**	**All**
Aluminum 3M	0.995	0.867	0.898
Aluminum 15M	0.976	0.752	0.757

	Standard Deviation Ratios		
	Positive	**Negative**	**All**
WTI 3M	0.903	0.793	0.758
WTI 15M	0.858	0.607	0.580

The results presented are also consistent with Samuelson's (1965) proposition that the variability of futures prices is an inverse function of the maturity. Note that the ratios on 15 months contracts are always inferior to ratios for 3 months forwards for both oil and copper, and hold for either sign of the interest-adjusted basis.

When I included the 6 months forward (future) contracts (with the sample between July 1997 and December 2008), results did not hold for 6 months forward copper and 3 months forward aluminum which have shown a greater ratio for the negative interest-adjusted basis sample. Results are posted in Table 8:

Table 8. Ratios of the Standard Deviation of Daily Forward (or Futures) Price Changes to the Standard Deviation of Daily Spot Price Changes

This table shows the ratios of the standard deviation of daily forward (or futures) price changes to the standard deviation of daily spot price changes providing data for both commodities in all sample, only positive and only negative interest-adjusted basis subsamples.

	Standard Deviation Ratios		
	Positive	**Negative**	**All**
copper 3M	0.999	0.971	0.967
copper 6M	0.998	1.187	1.143
copper 15M	0.979	0.910	0.925

	Standard Deviation Ratios		
	Positive	**Negative**	**All**
Aluminum 3M	0.935	0.975	0.946
Aluminum 6M	0.957	0.893	0.895
Aluminum 15M	0.995	0.747	0.768

	Standard Deviation Ratios		
	Positive	**Negative**	**All**
WTI 3M	0.913	0.849	0.804
WTI 6M	0.902	0.786	0.725
WTI 15M	0.870	0.666	0.617

In addition, in Table 9 are shown the results of the F-tests where de null hypothesis that the variance of daily changes of spot and forward prices are equal was tested at the 0.995 probability level. This table only includes 3 and 15 months forward contracts while table 10 includes 3, 6 and 15 months forwards.

For copper and aluminum, the tests in Table 9 did not rejected the null hypothesis for positive interest-adjusted basis sample, which is consistent with the prediction that shocks produce the same variability in spot and forward prices when the interest-adjusted basis is positive (i.e. inventory is high). Results for WTI were not consistent with that proposition once the hypothesis of equality of variances on spot and futures prices when the interest-adjusted basis is positive was rejected for both maturities. Despite of the rejection, we can note that the F-stat was always higher for negative tan for positive interest-adjusted basis.

Table 9. F-tests for Equality of Variances.

This table presents f-tests for equality of variances between spot and forward (futures) prices on the subsamples that include only positive and only negative values of the interest-adjusted basis. F-stat is the ratio between the variance of spot prices to the variance of forward (futures prices).

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	**var(3M)**	**Ratio**	**F-value**	**F-critical (-)**	**F-critical (+)**	**Hypothesis**
copper 3M positive	0.112%	0.111%	1.011	1.011	0.892	1.135	not-rejected
copper 3M negative	0.037%	0.028%	1.329	1.329	0.920	1.097	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(15M)]			
	var(spot)	**var(15M)**	**Ratio**	**F-value**	**F-critical (-)**	**F-critical (+)**	**Hypothesis**
copper 15M positive	0.092%	0.086%	1.068	1.068	0.874	1.160	not-rejected
copper 15M negative	0.033%	0.022%	1.531	1.531	0.925	1.090	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	**var(3M)**	**Ratio**	**F-value**	**F-critical (-)**	**F-critical (+)**	**Hypothesis**
Aluminum 3M positive	0.112%	0.111%	1.011	1.011	0.892	1.135	not-rejected
Aluminum 3M negative	0.037%	0.028%	1.329	1.329	0.920	1.097	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(15M)]			
	var(spot)	**var(15M)**	**Ratio**	**F-value**	**F-critical (-)**	**F-critical (+)**	**Hypothesis**
Aluminum 15M positive	0.034%	0.033%	1.049	1.049	0.920	1.097	not-rejected
Aluminum 15M negative	0.021%	0.012%	1.766	1.766	0.892	1.135	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	**var(3M)**	**Ratio**	**F-value**	**F-critical (-)**	**F-critical (+)**	**Hypothesis**
Oil 3M positive	0.129%	0.105%	1.225	1.225	0.894	1.132	rejected
Oil 3M negative	0.073%	0.046%	1.592	1.592	0.894	1.132	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(15M)]			
	var(spot)	**var(15M)**	**Ratio**	**F-value**	**F-critical (-)**	**F-critical (+)**	**Hypothesis**
Oil 15M positive	0.227%	0.167%	1.359	1.359	0.858	1.185	rejected
Oil 15M negative	0.060%	0.022%	2.716	2.716	0.928	1.087	rejected

When the 6 months contract was included (Table 10), results were held, showing that for aluminum and copper, variance of spot and forward contracts are equal when inventories are high, but the equality not hold when inventories are low. Again, tests for the crude oil did not sustain the theory.

Table 10. F-tests for Equality of Variances.

This table presents f-tests for equality of variances between spot and forward (futures) prices on the subsamples that include only positive and only negative values of the interest-adjusted basis. F-stat is the ratio between the variance of spot prices to the variance of forward (futures prices).

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	var(3M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
copper 3M positive	0.144%	0.144%	1.001	1.001	0.892	1.135	not-rejected
copper 3M negative	0.038%	0.036%	1.061	1.061	0.920	1.097	not-rejected

	Variance Ratios			F-test [H_0 var(spot)=var(15M)]			
	var(spot)	var(15M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
copper 6M positive	0.083%	0.083%	1.005	1.005	0.874	1.160	not-rejected
copper 6M negative	0.037%	0.052%	0.710	0.710	0.925	1.090	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(15M)]			
	var(spot)	var(15M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
copper 15M positive	0.126%	0.121%	1.044	1.044	0.874	1.160	not-rejected
copper 15M negative	0.031%	0.026%	1.208	1.208	0.925	1.090	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	var(3M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
Aluminum 3M positive	0.026%	0.025%	1.052	1.052	0.892	1.135	not-rejected
Aluminum 3M negative	0.031%	0.028%	1.117	1.117	0.920	1.097	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	var(3M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
Aluminum 6M positive	0.024%	0.022%	1.092	1.092	0.892	1.135	not-rejected
Aluminum 6M negative	0.027%	0.021%	1.253	1.253	0.920	1.097	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(15M)]			
	var(spot)	var(15M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
Aluminum 15M positive	0.054%	0.054%	1.009	1.009	0.892	1.135	not-rejected
Aluminum 15M negative	0.018%	0.010%	1.794	1.794	0.920	1.097	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	var(3M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
Oil 3M positive	0.161%	0.135%	1.200	1.200	0.894	1.132	rejected
Oil 3M negative	0.070%	0.050%	1.388	1.388	0.894	1.132	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(3M)]			
	var(spot)	var(3M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
Oil 6M positive	0.199%	0.162%	1.228	1.228	0.894	1.132	rejected
Oil 6M negative	0.067%	0.041%	1.618	1.618	0.894	1.132	rejected

	Variance Ratios			F-test [H_0 var(spot)=var(15M)]			
	var(spot)	var(15M)	Ratio	F-value	F-critical (-)	F-critical (+)	Hypothesis
Oil 15M positive	0.294%	0.223%	1.322	1.322	0.858	1.185	rejected
Oil 15M negative	0.055%	0.024%	2.254	2.254	0.928	1.087	rejected

In addition, instead of using variance ratios, I calculated the average ratios of the forward daily prices change to the spot daily prices change: *[F(t,T)-F(t-1,T-1)]/[S(t)-S(t-1)]*.

Table 11. – Ratio of the daily change in future/forward prices to the daily change in spot prices: [F(t,T)-F(t-1,T-1)]/[S(t)-S(t-1)]

This table shows the ratio of the daily change in future (forward) prices to the daily change in spot prices, providing data for both commodities in all sample, above median (positive) and under median (negative) interest-adjusted basis subsamples.

	Avg. Daily Change Ratios	
	Positive	**Negative**
aluminum 3M	1,004	0,831
aluminum 15M	0,983	0,719

	Avg. Daily Change Ratios	
	Positive	**Negative**
copper 3M	0,995	0,867
copper 15M	1,070	0,875

	Avg. Daily Change Ratios	
	Positive	**Negative**
WTI 3M	0,978	0,757
WTI 15M	0,681	0,662

Except for the 15 WTI, results in Table 11 are consistent with the proposition that spot prices are more variable then futures prices when the interest-adjusted basis negative than when it is positive. We can also note that the average of the ratios are close to 1.0 when the interest adjusted basis is positive (except for the 15 months WTI), showing that the daily changes on spot and futures prices are similar. I also tried to retest the result for the WTI calculating the ratio between the first (defining as positive) and fourth (defining as negative) quartiles of the interest adjusted basis, but results kept the inconsistence.

When I included the 6 months contract (Table 12), results were again mixed showing no evidence of difference on the average ratios on the positive and negative interest-adjusted basis samples for the 15 months copper and WTI.

Table 12. – Ratio of the daily change in future/forward prices to the daily change in spot prices: [F(t,T)-F(t-1,T-1)]/[S(t)-S(t-1)]

This table shows the ratio of the daily change in future (forward) prices to the daily change in spot prices, providing data for both commodities in all sample, above median (positive) and under median (negative) interest-adjusted basis subsamples.

	Avg. Daily Change Ratios	
	Positive	**Negative**
aluminum 3M	0,979	0,879
aluminum 6M	0,977	0,893
aluminum 15M	0,918	0,674

	Avg. Daily Change Ratios	
	Positive	**Negative**
copper 3M	0,943	0,940
copper 6M	0,998	0,829
copper 15M	0,852	0,893

	Avg. Daily Change Ratios	
	Positive	**Negative**
WTI 3M	0,997	0,755
WTI 6M	0,810	0,694
WTI 15M	0,721	0,693

6.3 The Response of Forward Prices to Changes in Spot Prices

The theory of storage and the shape of the convenience yield function (Figure 2) imply that at high inventory level, shocks produce roughly equal changes in current and expected spot prices. That said, consider the regression of the percent change in the forward price on the percent change in the spot price:

$$\text{Ln}[F(t,T)/F(t-1,T-1)] = \alpha + \beta\text{Ln}[S(t)/S(t-1)] + e(t) \qquad (4)$$

According to that implication, the slope β in (4) is close to 1.0 once 1.0 percent change in spot prices imply in roughly one percent change in expected spot price.

At lower inventory levels, smaller inventory responses are available meaning that shocks have a larger effect on the current than on expected spot prices because of the large change in convenience yield, meaning that changes in spot prices are associated with less than one-for-one changes in the expected spot prices.

The slopes for LME aluminum and copper in table 13 confirm this prediction, while results for WTI didn't show a close to 1.0 slope for the sample of positive interest-adjusted basis but presented a smaller slope for negative interest-adjusted basis than for positive ones.

Table 13. – Regressions of Daily Changes in Forward (Futures) Prices on Contemporaneous Daily Changes in Spot Prices: $Ln[F(t,T)/F(t-1,T-1)] = \alpha + \beta Ln[S(t)/S(t-1)] + e(t)$

This table presents the slope β, the standard deviation of β [S(β)] and the R^2 of the regressions of the daily changes in forward (futures) prices on contemporaneous daily changes in spot prices.

	Positive			Negative			All		
	β	S(β)	R^2	β	S(β)	R^2	β	S(β)	R^2
copper 3M	0.967	0.006	0.944	0.787	0.007	0.823	0.754	0.007	0.714
copper 15M	0.967	0.006	0.944	0.674	0.007	0.728	0.680	0.007	0.669

	Positive			Negative			All		
	β	S(β)	R^2	β	S(β)	R^2	β	S(β)	R^2
Aluminum 3M	0.991	0.005	0.978	0.853	0.006	0.879	0.805	0.006	0.840
Aluminum 15M	0.940	0.006	0.933	0.625	0.006	0.738	0.667	0.007	0.776

	Positive			Negative			All		
	β	S(β)	R^2	β	S(β)	R^2	β	S(β)	R^2
WTI 3M	0.859	0.007	0.905	0.735	0.005	0.860	0.688	0.005	0.824
WTI 15M	0.789	0.011	0.846	0.481	0.006	0.630	0.455	0.005	0.616

Again, results were also consistent with Samuelson's proposition that the difference between the variability of spot and futures prices increases with the maturity of the futures price. As we can see, slopes for 15 months contracts for the three commodities were always smaller than for 3 months contracts in all the situations.

When I included the 6 months contracts, results again held the consistence, showing inferior coefficients for the negative interest-adjusted basis samples, close to 1.0 slopes for the positive interest-adjusted basis samples (except for WTI) and coefficients inversely proportional to the contracts maturities.

Table 14. – Regressions of Daily Changes in Forward (Futures) Prices on Contemporaneous Daily Changes in Spot Prices: $Ln[F(t,T)/F(t-1,T-1)] = \alpha + \beta Ln[S(t)/S(t-1)] + e(t)$

This table presents the slope β, the standard deviation of β [S(β)] and the R^2 of the regressions of the daily changes in forward (futures) prices on contemporaneous daily changes in spot prices.

	Positive			Negative			All		
	β	S(β)	R^2	β	S(β)	R^2	β	S(β)	R^2
aluminum 3M	0,973	0,006	0,996	0,926	0,006	0,957	0,948	0,006	0,966
aluminum 6M	0,949	0,005	0,984	0,858	0,006	0,923	0,879	0,005	0,907
aluminum 15M	0,985	0,005	0,979	0,675	0,006	0,818	0,761	0,006	0,847

	Positive			Negative			All		
	β	S(β)	R^2	β	S(β)	R^2	β	S(β)	R^2
copper 3M	0,980	0,007	0,962	0,963	0,007	0,984	0,971	0,007	0,948
copper 6M	0,985	0,007	0,977	0,911	0,008	0,889	0,928	0,007	0,917
copper 15M	0,975	0,006	0,993	0,853	0,007	0,880	0,887	0,007	0,897

	Positive			Negative			All		
	β	S(β)	R^2	β	S(β)	R^2	β	S(β)	R^2
WTI 3M	0,873	0,008	0,914	0,805	0,011	0,901	0,821	0,009	0,904
WTI 6M	0,856	0,010	0,900	0,722	0,008	0,844	0,787	0,011	0,877
WTI 15M	0,809	0,007	0,864	0,553	0,009	0,689	0,673	0,011	0,717

7 FINAL REMARKS

In this study I extended the methodology applied by Fama and French (1988) to test the proposition of the theory of storage that the marginal convenience yield on inventory falls at a decreasing rate as inventory increases.

This proposition implies that futures prices are less variable than spot prices when inventory is low, but spot and futures prices have similar variability when inventory is high, so I tested this hypothesis by analyzing the behavior of aluminum, copper and WTI crude oil spot and futures prices from 1990 to 2008. The sample included data for spot, 3, 6 and 15 months forward aluminum and copper from LME, and 1, 4, 7 and 16 months WTI futures from NYMEX.

The tests on the variability of the interest-adjusted basis provided mixed evidence that the variability is grater when it is positive. For aluminum and 15 months forward copper the results were consistent wit that proposition, while for 3 months copper the standard deviations were not significantly different and for both maturities of WTI, the average deviations were larger when the interest-adjusted basis is positive.

In addition, I performed tests on the relative variability of spot and forward prices, analyzing the ratio of the standard deviation of daily percent changes on spot and forward prices, and the average ratio of daily prices changes (differences) on spot and forward prices. Obtained results were mostly in line with the theory of storage prediction, showing that spot prices are more variable then forward prices when the interest-adjusted basis is negative, but have roughly the same variability when inventory is low (i.e. interest-adjusted basis is negative).

Lastly, I performed a linear regression of the percent change in the forward prices on the percent changes in the spot prices. The equation is described as follows:

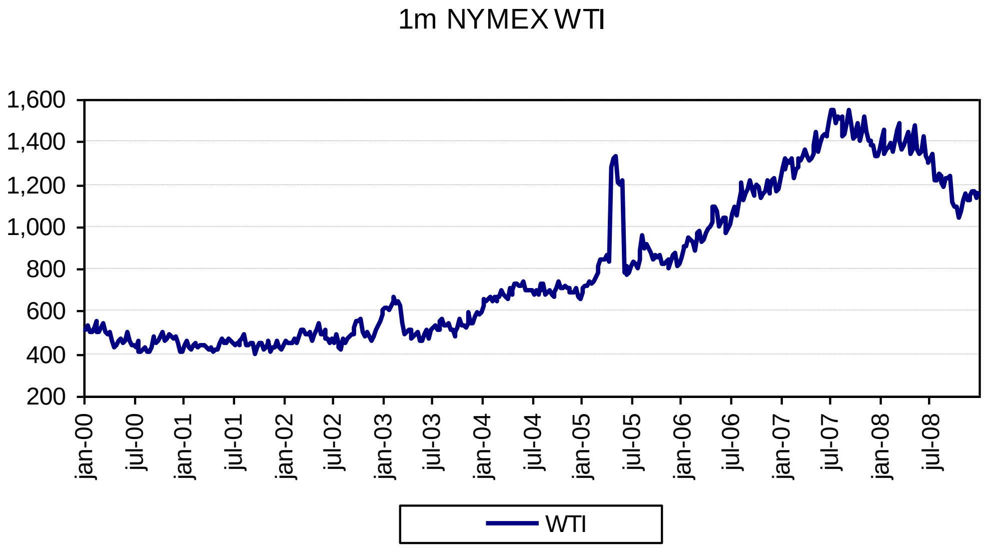
$$\mathrm{Ln}[F(t,T)/F(t-1,T-1)] = \alpha + \beta \mathrm{Ln}[S(t)/S(t-1)] + e(t)$$

According to the prediction that shocks produce more independent variation in spot and forward prices when inventory is low, but spot and forward prices have roughly the same variation when inventory is high, the slope β should be 1.0 for positive values of the interest-adjusted basis, and less than 1.0 for negative basis.

Again, results were consistent with the theory, presenting a close to 1.0 slope for the sample with positive interest-adjusted basis, and a smaller slope for negative values.

The inconsistence of some results found in this study can be attributed to the large increase of speculative capital in commodities markets in the last years. Once the convenience yield is the benefit of holding the physical commodity, speculators may cause some distortion in the shape of the function presented in Figure 3, as they do not use to carry inventories. The sharp increase in leverage capacity and difference of liquidity between maturities can also explain some of the unexpected results.

Figure 5 show historical data on the open interest of non-commercial positions on NYMEX 1 month future WTI and COMEX 1 month future Copper. As we can note, the amount and variability of non-commercial positions has been increasing in the last years, what certainly brings more volatility to the market. The data is provided by the U.S, Commodity Futures Trading Commission on a weekly basis.



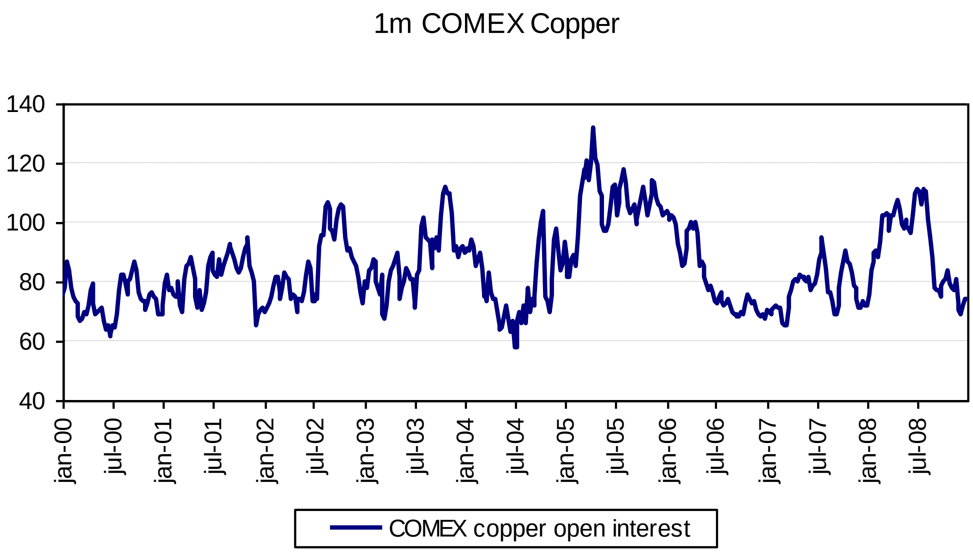


Figure 5. 1 Month Future NYMEX WTI non-commercial positions open interest (thousand contracts) and 1 Month Future COMEX Copper non-commercial positions open interest (thousand contracts).

This figure shows the non-commercial positions open interest for 1 month future NYMEX WTI and 1 month future COMEX copper. As we can note, both the amount and variability of non-commercial positions open interest have been increasing along the years, bringing more volatility and distortions to the commodities market.

The increasing presence of speculative money in commodities market has brought to this market distortions in prices and volatilities, and preventive actions are constantly being implemented by trading commissions in order to keep the efficiency of the market.

Slade and Thille (2005) showed that trading volume and the volatility of spot prices have a positive time series relationship. Using LME data on base metals for a period between January 1990 and January 1999, they found evidence that the relationship between volume and volatility of spot prices is positive and highly significant.

In the same work, the authors also studied the impact of industrial fundamentals in commodities prices behavior. Based on traditional market structure models they found that price levels are positively related to product market concentration and that the financial market activity and increased liquidity appears to be associated with lower prices.

The theory described by the Industrial Organization can also provide some explanation to some inconsistencies found in my tests once I have not incorporated information on industry concentration, costs structure and regulation in my work.

In the early 1990's the head of Sumitomo's metal-trading division Yasuo Hamanaka used Sumitomo's size and large cash reserves to both corner and squeeze the copper market[2] via the LME keeping prices artificially hight for nearly a decade by getting long in both physical holdings and futures in copper, and using Sumitomo's large cash position to force anyone shorting copper to deliver the goods or close out their position at a premium.

Despite of cited discrepancies, results were mostly in line with those encountered by Fama & French (1988), especially in the analysis of the relative variability of spot and forward prices and the response of forward prices to changes in spot prices, where I could corroborate the theory of storage prediction supply and demand shocks produce roughly the same variability on spot and futures prices when inventory is high but spot prices vary more than futures prices when inventory is high.

Even without performing the tests introduced by Ng and Pirrong, our results also gives us evidence that the interest-adjusted basis has a statistically significant effect on the variances of both spot and forward returns and for the correlation between them.

[2] More details on "The copper king" copper price squeeze may be found at http://www.investopedia.com/articles/financial-theory/08/mr-copper-commodities.asp

The discrepancies found in some tests brings us the idea that changes in commodities market participants, leverage capacity and liquidity of those markets may be causing distortions in prices behavior bringing them out of fundamentals sometimes. This study can be extended by applying the encountered results in hedging strategies like repeating Ripple and Moosa (2007) tests segregating the samples in positive and negative interest adjusted basis periods in order to calculate the hedge ratios.

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9 APPENDIX

Tables 15 to 23 resume the sample showing yearly average and median prices, as well as standard deviations, maximum and minimum values for each series of LME Aluminum and Copper, and NYMEX WTI crude oil.

Table 15. Aluminum – Spot Price – London Mercantile Exchange (Prices quoted in US dollars per metric ton)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of spot LME aluminum on an yearly basis from 1990 to 2008.

	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	251	1,643.94	1,561.00	192.78	2,245.00	1,380.00
1991	251	1,301.62	1,282.00	142.18	1,569.00	1,073.50
1992	242	1,259.74	1,275.25	56.66	1,344.50	1,137.50
1993	250	1,140.03	1,141.25	53.55	1,244.00	1,019.00
1994	251	1,478.04	1,438.50	230.22	2,001.50	1,111.00
1995	252	1,805.62	1,794.00	121.73	2,146.50	1,624.00
1996	254	1,504.22	1,493.00	91.42	1,674.50	1,286.00
1997	253	1,600.14	1,599.00	54.36	1,779.00	1,490.00
1998	252	1,357.24	1,332.63	76.71	1,529.50	1,226.75
1999	256	1,366.15	1,379.00	127.54	1,630.00	1,136.20
2000	258	1,549.47	1,551.00	77.56	1,754.50	1,417.75
2001	251	1,446.68	1,445.25	113.31	1,716.00	1,242.50
2002	251	1,350.12	1,357.25	37.04	1,436.00	1,277.75
2003	253	1,433.11	1,423.25	62.29	1,588.75	1,310.50
2004	254	1,719.08	1,704.13	84.86	1,968.00	1,546.50
2005	252	1,899.66	1,860.75	143.16	2,282.75	1,670.25
2006	252	2,569.91	2,525.00	170.58	3,186.75	2,281.50
2007	252	2,640.60	2,693.13	174.87	2,938.00	2,334.50
2008	254	2,576.42	2,735.00	493.37	3,271.25	1,431.00

Table 16. Aluminum – 3 Months Forward Price – London Mercantile Exchange (Prices quoted in US dollars per metric ton)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of 3 months forward LME aluminum on an yearly basis from 1990 to 2008.

	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	251	1,642.57	1,625.00	91.13	1,835.00	1,460.00
1991	251	1,440.32	1,435.00	133.19	1,670.00	1,210.00
1992	254	1,372.33	1,390.00	55.56	1,460.00	1,230.00
1993	252	1,252.31	1,252.00	58.72	1,367.00	1,130.00
1994	246	1,530.12	1,525.00	177.98	1,895.00	1,208.00
1995	252	1,806.62	1,788.00	64.50	2,019.00	1,663.00
1996	253	1,623.58	1,627.00	69.75	1,773.00	1,443.00
1997	253	1,635.65	1,640.00	19.75	1,674.50	1,572.75
1998	252	1,450.23	1,435.13	66.08	1,575.25	1,324.50
1999	259	1,436.25	1,456.75	108.58	1,633.75	1,242.00
2000	258	1,557.65	1,550.50	42.17	1,673.00	1,478.75
2001	251	1,479.46	1,505.00	69.21	1,576.50	1,317.75
2002	248	1,410.89	1,412.13	33.37	1,490.00	1,342.75
2003	252	1,425.78	1,415.75	48.25	1,557.00	1,346.25
2004	254	1,654.68	1,648.75	54.70	1,843.00	1,544.00
2005	252	1,812.29	1,798.75	101.67	2,125.50	1,658.00
2006	252	2,463.44	2,462.00	129.27	2,898.00	2,120.00
2007	252	2,632.40	2,623.00	84.78	2,848.50	2,436.00
2008	254	2,740.72	2,919.25	463.72	3,431.50	1,619.00

Table 17. Aluminum – 15 Months Forward Price – London Mercantile Exchange (Prices quoted in US dollars per metric ton)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of 15 months forward LME aluminum on an yearly basis from 1990 to 2008.

	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	251	1,638.37	1,581.00	151.89	2,130.00	1,407.00
1991	251	1,331.94	1,315.00	143.82	1,598.00	1,100.00
1992	254	1,278.09	1,296.00	62.26	1,370.50	1,126.50
1993	253	1,160.82	1,162.00	54.46	1,266.50	1,040.50
1994	252	1,502.80	1,468.50	230.41	1,999.50	1,129.00
1995	252	1,831.41	1,816.00	119.71	2,188.00	1,657.00
1996	254	1,536.14	1,527.50	88.38	1,698.00	1,323.00
1997	253	1,620.60	1,622.50	44.16	1,762.50	1,517.00
1998	252	1,379.51	1,359.50	77.65	1,545.00	1,241.00
1999	254	1,390.78	1,405.00	132.07	1,650.00	1,159.00
2000	256	1,567.14	1,568.00	70.35	1,750.00	1,437.00
2001	251	1,455.34	1,468.00	96.25	1,633.00	1,259.00
2002	251	1,364.68	1,374.00	36.06	1,455.00	1,292.50
2003	253	1,429.09	1,413.00	63.39	1,600.00	1,327.50
2004	254	1,723.75	1,715.00	75.71	1,965.00	1,559.00
2005	252	1,900.96	1,870.00	134.49	2,282.00	1,688.00
2006	252	2,595.25	2,565.00	160.11	3,185.00	2,283.00
2007	252	2,663.94	2,706.50	149.94	2,895.00	2,387.00
2008	254	2,623.02	2,785.00	492.97	3,317.00	1,471.00

Table 18. Copper – Spot Price – London Mercantile Exchange (Prices quoted in US dollars per metric ton)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of spot LME copper on an yearly basis from 1990 to 2008.

Year	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	250	2.662,50	2.646,62	217,22	3.387,34	2.193,43
1991	252	2.337,38	2.351,01	107,49	2.624,55	2.119,28
1992	253	2.283,07	2.231,32	132,39	2.576,55	2.075,57
1993	253	1.911,15	1.895,80	206,13	2.387,01	1.595,80
1994	252	2.312,54	2.399,00	371,94	3.088,00	1.719,80
1995	252	2.937,47	2.939,50	103,86	3.235,00	2.716,00
1996	253	2.291,09	2.295,00	295,52	2.841,00	1.830,00
1997	253	2.275,70	2.356,00	257,19	2.720,00	1.699,00
1998	251	1.653,22	1.652,50	90,99	1.880,00	1.438,00
1999	252	1.573,66	1.602,00	149,40	1.846,00	1.354,00
2000	252	1.814,26	1.812,75	76,68	2.009,00	1.607,00
2001	251	1.577,77	1.556,50	146,05	1.837,00	1.319,00
2002	251	1.557,50	1.572,00	62,47	1.689,50	1.421,00
2003	253	1.779,87	1.711,00	182,19	2.321,00	1.544,50
2004	254	2.868,34	2.870,00	218,02	3.287,00	2.337,00
2005	252	3.683,64	3.596,25	428,06	4.650,00	3.072,00
2006	252	6.730,60	7.183,75	1.163,87	8.788,00	4.537,00
2007	252	7.126,35	7.379,75	850,06	8.301,00	5.225,50
2008	254	6.951,52	7.675,25	1.895,22	8.985,00	2.770,00

Table 19. Copper – 3 Months Forward Price – London Mercantile Exchange (Prices quoted in US dollars per metric ton)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of 3 months forward LME copper on an yearly basis from 1990 to 2008.

	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	250	2.558,08	2.533,65	168,98	2.958,40	2.180,70
1991	252	2.306,94	2.301,50	90,15	2.600,00	2.123,40
1992	257	2.301,62	2.254,00	126,82	2.576,00	2.096,80
1993	249	1.917,38	1.894,40	202,28	2.388,90	1.619,20
1994	251	2.315,87	2.410,00	355,38	3.029,00	1.740,20
1995	252	2.863,66	2.877,50	102,64	3.071,00	2.650,00
1996	254	2.221,80	2.155,00	281,55	2.696,00	1.745,00
1997	253	2.219,17	2.262,00	205,07	2.592,00	1.726,00
1998	252	1.674,26	1.670,00	88,04	1.894,00	1.467,00
1999	256	1.607,88	1.639,50	152,22	1.888,50	1.380,00
2000	257	1.839,66	1.836,00	75,28	2.022,00	1.653,00
2001	251	1.598,65	1.581,00	141,98	1.830,50	1.338,50
2002	251	1.577,73	1.589,00	61,58	1.706,00	1.445,00
2003	253	1.788,63	1.720,00	174,75	2.301,00	1.575,00
2004	254	2.790,48	2.792,50	188,20	3.150,00	2.336,00
2005	252	3.506,87	3.356,50	422,15	4.483,00	2.912,00
2006	252	6.678,80	7.087,50	1.175,33	8.600,00	4.440,00
2007	252	7.103,03	7.315,00	798,80	8.320,00	5.340,00
2008	254	6.886,23	7.620,00	1.834,47	8.730,00	2.845,00

Table 20. Copper – 15 Months Forward Price – London Mercantile Exchange (Prices quoted in US dollars per metric ton)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of 15 months forward LME copper on an yearly basis from 1990 to 2008.

	Observations	**Mean**	**Median**	**St. Deviation**	**Maximum**	**Minumum**
1990	251	2.385,63	2.371,32	89,46	2.585,38	2.177,90
1991	254	2.279,40	2.284,03	114,81	2.479,09	1.290,00
1992	254	2.403,65	2.361,15	99,30	2.633,09	2.257,49
1993	252	1.995,65	1.942,48	207,91	2.453,22	1.707,00
1994	252	2.223,13	2.320,00	218,91	2.500,00	1.822,00
1995	252	2.524,67	2.520,00	53,73	2.650,00	2.390,00
1996	253	2.083,91	2.005,00	195,24	2.410,00	1.800,00
1997	253	2.067,57	2.090,00	95,55	2.230,00	1.807,00
1998	252	1.714,41	1.703,50	72,79	1.860,00	1.554,50
1999	259	1.677,08	1.690,75	143,30	1.944,50	1.458,00
2000	258	1.854,96	1.850,75	60,64	1.992,75	1.722,25
2001	250	1.648,33	1.647,38	124,87	1.842,50	1.400,75
2002	248	1.632,95	1.639,25	56,56	1.754,50	1.512,50
2003	252	1.797,92	1.746,75	145,13	2.229,25	1.611,00
2004	254	2.468,42	2.466,50	116,95	2.743,00	2.243,00
2005	252	2.981,55	2.863,50	323,59	3.847,00	2.538,00
2006	252	6.048,96	6.603,00	1.065,88	7.400,00	3.781,00
2007	252	6.662,51	6.822,50	679,24	7.675,00	5.087,00
2008	254	6.682,93	7.361,50	1.637,82	8.285,00	2.935,00

Table 21. West Texas Intermediate – 1 Month Future Price – New York Mercantile Exchange (Prices quoted in US Dollars per barrel)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of 1 month future NYMEX WTI crude oil prices on an yearly basis from 1990 to 2008.

	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	253	24,51	22,36	6,60	40,42	15,30
1991	252	21,50	21,35	1,90	32,00	17,91
1992	252	20,58	20,70	1,29	22,89	17,86
1993	251	18,48	18,58	1,71	21,07	13,91
1994	251	17,19	17,47	1,70	20,75	13,93
1995	248	18,42	18,34	0,87	20,52	16,87
1996	252	22,03	21,93	2,24	26,57	17,45
1997	252	20,60	20,20	1,83	26,62	17,60
1998	251	14,36	14,34	1,57	17,82	10,72
1999	250	19,30	19,38	4,51	27,07	11,37
2000	249	30,26	30,25	2,91	37,20	23,85
2001	247	25,95	27,21	3,53	32,19	17,45
2002	250	26,15	26,65	3,19	32,72	17,97
2003	250	30,99	30,78	2,61	37,83	25,24
2004	249	41,47	40,77	5,78	55,17	32,48
2005	251	56,70	57,34	6,23	69,81	42,12
2006	251	66,25	65,85	5,56	77,03	55,81
2007	252	72,36	69,70	12,77	98,18	50,48
2008	253	99,75	104,83	28,42	145,29	33,87

Table 22. West Texas Intermediate – 4 Months Future Price – New York Mercantile Exchange (Prices quoted in US Dollars per barrel)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of 4 months future NYMEX WTI crude oil prices on an yearly basis from 1990 to 2008.

	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	253	23,69	21,32	4,78	35,95	18,02
1991	253	20,81	20,97	1,54	26,35	17,35
1992	252	20,56	20,70	1,07	22,53	18,10
1993	251	19,00	19,07	1,50	21,14	15,06
1994	251	17,06	17,40	1,28	19,53	14,46
1995	250	17,89	17,88	0,74	19,65	16,56
1996	252	20,18	19,35	2,11	24,44	16,91
1997	252	20,50	20,25	1,24	24,56	18,18
1998	251	15,34	15,37	1,46	18,25	11,61
1999	249	18,79	19,12	3,86	24,75	11,78
2000	249	28,21	28,06	2,62	34,56	22,75
2001	248	25,76	26,74	3,03	29,97	18,27
2002	250	25,62	25,95	2,55	29,44	19,27
2003	250	29,17	29,18	1,94	33,37	24,87
2004	249	40,27	39,53	5,99	53,58	30,76
2005	251	58,11	59,19	6,33	70,41	42,19
2006	251	68,97	67,77	5,19	79,71	61,13
2007	251	72,95	70,27	10,73	95,08	53,19
2008	253	100,28	103,09	27,01	146,43	41,50

Table 23. West Texas Intermediate – 16 Months Future Price – New York Mercantile Exchange (Prices quoted in US Dollars per barrel)

This table shows the number of observations, mean, median, standard deviation, maximum and minimum values of 16 months NYMEX WTI crude oil prices on an yearly basis from 1990 to 2008.

	Observations	Mean	Median	St. Deviation	Maximum	Minumum
1990	252	21,66	20,77	2,22	27,45	18,49
1991	253	20,13	20,42	0,94	22,28	17,58
1992	252	20,04	20,14	0,62	21,19	18,68
1993	250	19,59	19,63	0,86	21,02	17,23
1994	251	17,60	17,73	0,64	18,95	16,08
1995	250	17,56	17,54	0,46	18,53	16,65
1996	252	18,17	17,88	1,01	20,56	16,53
1997	252	19,80	19,80	0,38	20,90	18,58
1998	251	16,93	17,14	1,02	18,79	14,12
1999	249	17,20	17,89	1,98	19,82	13,23
2000	249	23,86	24,00	2,22	28,96	18,99
2001	247	23,55	23,97	1,53	25,80	19,59
2002	250	23,34	23,71	1,19	24,93	20,04
2003	250	25,47	25,49	0,96	28,06	23,46
2004	249	36,08	35,04	5,43	47,05	27,79
2005	251	56,83	58,99	7,32	68,42	39,99
2006	251	70,96	69,71	3,99	80,25	64,20
2007	251	72,74	71,32	7,48	89,44	57,17
2008	253	100,83	99,99	23,52	145,62	52,55