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Spread, inventory and spot price volatility in the platinum market

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Abstract

The central idea of the theory of storage is that the level of inventory influences the effect that changes in the demand-and-supply conditions have on spot and futures prices. With the use of monthly data for the period January 1992 to January 2010, I find that the predictions of the theory of storage do not always hold in the platinum market. In conflict with the theoretical predictions, I find that: i) demand-and-supply shocks will have the same effect on spot and futures prices, regardless of the level of inventory; and ii) changes in spot prices have very similar effects on the changes in futures prices when inventory is high and when it is low. In support of the theory of storage, I find a significant negative correlation between the volatility of spot prices and inventory throughout the sample period. Thereafter, I test the forecasting ability of the spot price volatility by employing a GARCH-t(1,1) model and find that volatility can be forecast fairly accurately for short periods, during which the spot prices are somewhat stable.

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1 Introduction

The increase in demand for platinum over the past two decades has led me to research two important factors relating to the platinum market: the shape of the futures curve and spot price volatility. These factors are important to both inventors and hedgers as they play a key role in trading and other investment activities.

The increase in demand for this precious metal comes from many of its applications. According to research by Matthey (2009a, p. 32-33 of 36), the largest use for platinum by demand is as a jewellery metal, while the second largest use is as an autocatalyst in the automotive industry. It goes on to show that at the end of 2009, these two applications alone were responsible for over 83% of the total platinum demand. For the period 1990 to 2009, jewellery demand increased by 1 085 000 ounces whereas gross autocatalyst demand increased by 945 000 ounces (Matthey 1999, 2009a). Platinum is also used extensively in industrial applications, such as in the production of glass; in the development of platinum-based drugs to treat a wide range of cancers; and to increase the capacity of hard disks. Other uses for platinum include direct investment and the manufacturing of watches (Matthey 2009a, p. 32-33 of 36).

Since platinum is produced in a number of countries - principally in South Africa, Russia and North America (Matthey 2009a, p. 32-33 of 36) - and is consumed internationally - mainly in Japan, China and Europe (Matthey 2009a, p. 32-33 of 36) - the collection of reliable inventory data presents a problem. In order to get around this, I employ the suggestion made by Fama and French (1987) who use the detrended interest-adjusted spread¹, or the detrended slope of the futures curve, as a proxy for inventory.

My goal in this paper is to pay particular attention to the spot price volatility as well as to the shape of the futures curve, which is determined by the difference between the current futures price and the expected future spot price. The relationship between the shape of the futures curve and the spot price volatility is analysed by exploiting the implications of the theory of storage. This theory, as first suggested by Kaldor (1939), Working (1948, 1949), Brennan (1958) and Telser (1958), asserts that the way in which changes in demand-and-supply conditions affect the futures and spot prices depends upon the inventory level. Since the theory of storage suggests, amongst other things, that the spot price volatility is time-varying, and because volatility plays an important role in investment decisions, a Generalised Autoregressive Conditional Heteroscedastic model that incorporates a Student's t-distribution (GARCH-t) is used to model and forecast the spot price volatility.

With the use of monthly data over the period January 1992 to January 2010, I found that the empirical results often conflict with theoretical predictions. After comparing the variability of the spot and futures returns, I discover that demand-and-supply shocks have the same effect

¹I detrend the interest-adjusted spread in such a way that I remove the dependency on the particular interest rate that is used.

on spot and futures returns, irrespective of the level of inventory. In the regression of the percentage changes in futures prices on the percentage changes in spot prices, I find that the coefficient of the percentage changes in spot prices is not significantly different from one where inventory is either high or low. Therefore, changes in spot prices have a similar effect on changes in futures prices regardless of the inventory level. The Spearman rank tests confirm this, as there appears to be a significant positive relationship between the percentage changes in spot prices and the percentage changes in futures prices, irrespective of the level of inventory.

The Spearman rank tests also show that, as the theory predicts, there is a significant negative correlation between the annualised volatility of spot prices and inventory, and this correlation appears to decrease as inventory declines.

The GARCH-t(1,1) models indicate that the volatility of the spot prices can be forecast fairly accurately for short periods when prices during the prediction period exhibit changes and trends that are relatively similar to those during the sample period. Although this makes intuitive sense, it does not provide much insight into the reasons behind the changes in volatility nor is it thought to be useful for determining any volatility trading strategies.

Section 2 below gives the background to the theory of storage and discusses the previous literature relating to the study of this theory and GARCH models. The theory behind the tests performed is given in section 3, and section 4 explains the outline of platinum price movements for the period January 1992 to January 2010. The data and methodology used are summarised in section 5. Section 6 gives the empirical results, and section 7 concludes.

2 The fundamental relationship between inventory, futures prices and spot prices

2.1 The theory of storage

The theory of storage, as founded by Kaldor (1939), Working (1948, 1949), Brennan (1958) and Telser (1958), describes a relationship between inventory, futures prices and spot prices. Central to this theory is the concept of a convenience yield, which Kaldor (1939) introduced in an attempt to explain the reason for inverse carrying costs that arise when futures prices are below spot prices; or when the prices of deferred futures are below those of near futures. The intuition behind this is that, when futures prices are below spot prices, or do not exceed spot prices by enough to cover interest and warehousing costs, storers must get some other return from inventory. The convenience yield is earned by the inventory-holder of a commodity as stocks that are readily available enable the holder to respond more efficiently - in terms of both lower costs and less delay - to sudden increases in demand relative to supply (Kaldor 1939).

Let $F(t, T)$ be the futures price at time t for delivery of a commodity at time T . Let $S(t)$ be the spot price of the commodity at time t . As Fama and French (1988, p. 1076) explain, the theory of storage states that the return from buying a commodity at t and shorting a futures contract at t with expiry at T is equal to the interest foregone during the storage of the commodity, plus the storage costs less the marginal convenience yield:

$$F(t, T) - S(t) = [S(t)R(t, T) + C(t, T) - Y(t, T)][T - t] \quad (1)$$

where:

$F(t, T)$ and $S(t)$ are defined as above;

$R(t, T)$ is the annual interest rate over the period $T - t$;

$C(t, T)$ is the annual cost of storage determined by demand-and-supply conditions; and

$Y(t, T)$ is the marginal convenience yield derived from an additional unit of inventory.

By rearranging equation 1, I find:

$$\frac{F(t, T) - S(t)[1 + R(t, T)(T - t)]}{S(t)} = \frac{[C(t, T) - Y(t, T)][T - t]}{S(t)} \quad (2)$$

The left hand side of equation 2 represents the interest-adjusted spread of the forward curve relative to the spot price. This is observable since $F(t, T)$, $S(t)$ and $R(t, T)$ are easily obtained from the futures markets. The above equation relates the interest-adjusted spread to the difference between the relative storage costs, $c(t, T) = C(t, T)/S(t)$, and the relative marginal convenience yield, $y(t, T) = Y(t, T)/S(t)$.

Brennan (1958) and Telser (1958) find that at low levels of inventory, the relative marginal convenience yield is high, and vice versa. They also find that the marginal convenience yield does not decrease directly in line with an increase in inventory, but rather falls at a decreasing rate. This is illustrated in Figure 1 below.

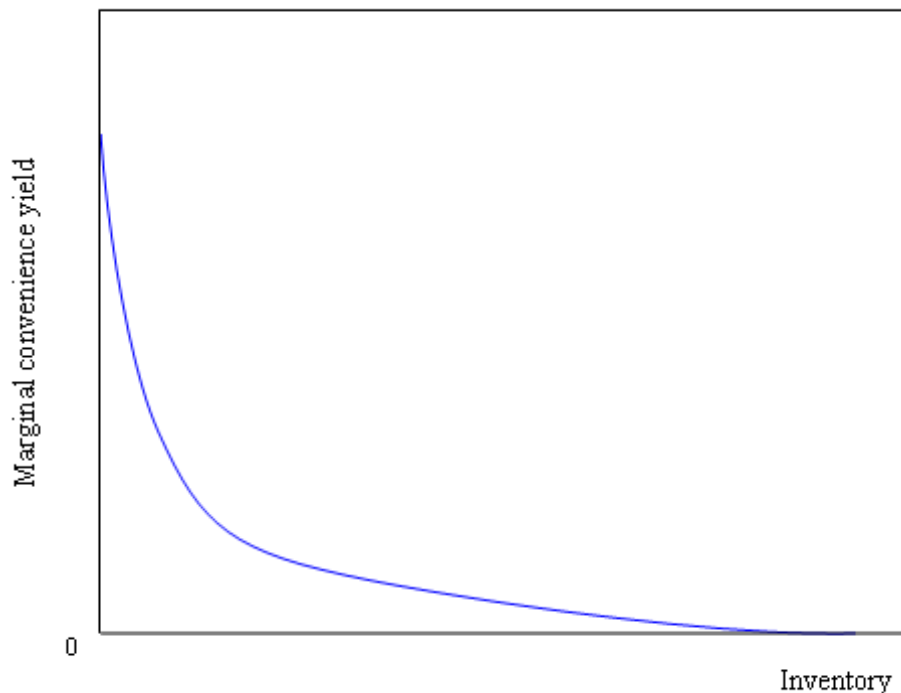


Figure 1: The marginal convenience yield against inventory

As can be seen in Figure 1, it is assumed that there is some level of stock for which the relative marginal convenience yield is zero. This means that if the holder of inventories were to increase his/her stocks above this level, he/she would not be rewarded by any additional convenience yield. Figure 1 also shows that the relative marginal convenience yield may never be less than zero. If it is, speculators will be able to earn an arbitrage profit by selling a futures contract, buying the underlying commodity and storing it until the futures contract expires (Ng & Pirrong 1994, p. 207).

At low inventory levels, the marginal convenience yield will be greater than the cost of storage, causing the interest-adjusted spread to be negative. As inventory increases and the marginal convenience yield declines, the interest-adjusted spread will increase to the cost of storage. This is illustrated in Figure 2 below.

Another reason for this positive relationship between interest-adjusted spread and inventory is arbitrage. As Ng and Pirrong (1994, p. 206) explain, arbitrage guarantees that the convenience yield affects the relationship between futures and spot prices. The holders of the

commodity will earn a convenience yield, whereas the owners of the futures contract will not. Therefore, the convenience yield will decrease the futures price relative to the spot price, and thus giving the relationship we see in Figure 2.

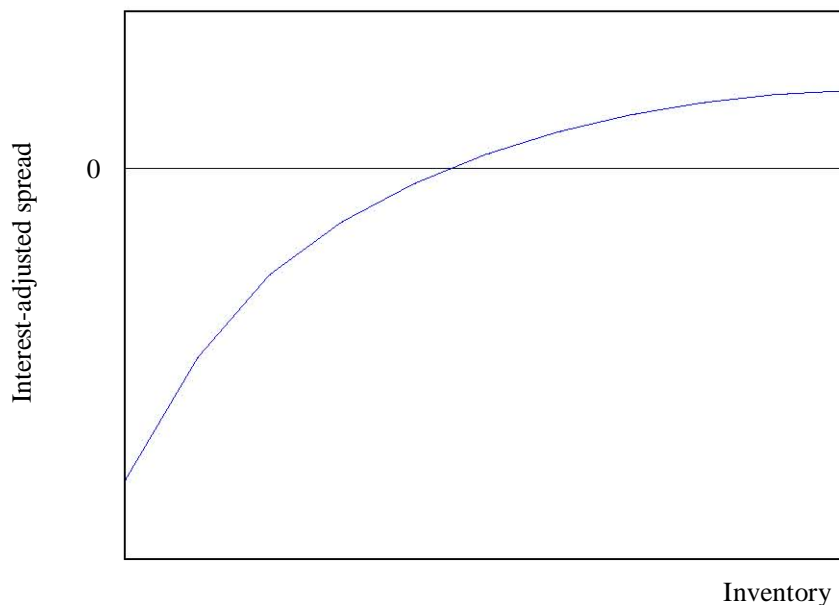


Figure 2: The interest-adjusted spread against inventory

2.2 Implications of the theory of storage

Although other factors will affect commodity price volatility, Currie et. al (2010) explain that it is predominantly demand-and-supply shocks that drive commodity price volatility. If the market is unable to physically deal with these shocks, prices will be forced to move and thus increase the volatility of the commodity. The magnitude of these movements will depend upon the level of inventory in the market, which is explained in further detail below. Geman (2005, p. 23-24) explains that it is the changes in the expectations of future demand-and-supply conditions that will cause the futures price to move. There are a number of factors that could cause a change in the demand-and-supply conditions. For example, a change in technology that improves the rate at which the commodity is mined would increase supply. However, this change in technology may take some time to implement fully, and thus only future supply is expected to increase, and not current supply. *Ceteris paribus*, this may lead to a large change in futures prices, while spot prices remain constant.

Using the fact that futures and spot price volatilities are largely driven by changes in expected and current demand-and-supply conditions, the implications arising from the relationships depicted in figures 1 and 2 can be explained. Firstly, as described by Fama and French (1988, p.1077), suppose there is a permanent increase in current and future demand of a commodity. When inventory is low, the response of suppliers is small since the marginal convenience yield rises quickly as inventory is used to meet the sudden increase in demand. Thus, the shock will have a large impact on the current spot price whereas the change in the futures price will be smaller. This is because the market will expect the producers of the commodity to increase the supply in the long run, since long-run supply is assumed to be elastic. When inventory is high, however, the marginal convenience yield is almost flat. As a result, suppliers are able to use a large amount of inventory to meet the unexpected demand increase without there being a large change in the convenience yield. This implies that the inventory response reduces the effect of the shock on current spot price (particularly when measured relative to the futures price). Therefore, the spot return variance, relative to the futures return variance, will decrease as inventory increases. Another result is that, when inventories are high, the interest-adjusted spread is less variable than when inventories are low.

Ng and Pirrong (1994, p. 209) point out a second implication, namely, when there are permanent shocks to both the current and future supply or temporary shocks to either the current demand or current supply, the predictions about the relative changes in the current spot and futures prices are similar to those for a permanent demand shock. To illustrate this postulate, suppose there is a sudden decline in supply or a similar increase in demand. A decrease in inventory in response to the shocks results in supply conditions becoming more constrained, which will reduce the elasticity of supply. As explained above, when inventories are low and supply is less elastic, the volatility of spot prices will be larger than that of futures prices. A sudden increase in supply or a similar decrease in demand would result in a more elastic supply, due to there being a rise in inventory. This would lead to the variability of spot and futures prices being more or less the same.

A third implication, as illustrated by Ng and Pirrong (1994, p. 211), is that when inventories are high, the correlation between spot and futures prices is equal to one. This correlation, however, will decrease as inventories fall. This can be seen by the above implications. When inventories are large, spot and futures prices move closely together in response to a demand-and-supply shock. As inventories decline, the spot and futures prices begin to react differently to changes in demand-and-supply conditions, thus causing the correlation to fall.

Geman (2005, p. 28) and Geman and Ohana (2009) both explain that spot price volatility is negatively related to inventory. To see this, consider the reasoning behind the first two implications; particularly the response of inventory, and the response of the current spot price, to demand-and-supply shocks. As explained in more detail above, when inventory is high, the current spot price should not vary by large amounts, and vice versa. Therefore, spot price

volatility and inventory must be negatively correlated.

The last implication considered here is that spot price volatility varies over time. It has been well documented by a number of authors (cf. Froot 1989, p. 335) that most financial time series data sets exhibit conditional heteroskedasticity. Froot (1989) continues to explain that, since there are often large and predictable changes in variance, conditional heteroskedasticity is an important feature of financial data.

2.3 Previous empirical findings

A number of papers study the relationship between the futures-spot price spread of various commodities and the inventory of the commodity. Fama and French (1987), for example, look at the theory of storage, and also consider the view that futures prices are made up of an expected risk premium and a forecast of future spot prices, to study the behaviour of futures prices for 21 commodities. The authors use monthly observations for the period starting January 1967 to May 1984 to test the two different theories and use the interest-adjusted spread as a proxy for inventory. They find that, in general, futures prices are poor predictors of future spot prices, particularly for metals, with only 10 out of the 21 commodities showing evidence of forecasting abilities, with none of these being metals. The authors also find that the variation of the interest-adjusted spread is low for metals since storage costs are low relative to the value of the metal and metals do not exhibit any seasonal variation in terms of supply and demand.

Fama and French (1988) test the theory of storage based on the hypothesis that the marginal convenience yield on inventory of various metals declines, but at a decreasing rate. To do this, they assess the daily volatility of futures and spot prices when inventory is high and when inventory is low. The authors use the interest-adjusted spread as a proxy for inventory because of the lack of reliable inventory data for metals. They find that, for industrial metals, the results are in line with what the theory predicts - when inventory is low, the variability of the interest-adjusted spread is high; spot prices are more variable than futures prices; and there is more independent variation in spot and futures prices compared to when inventory is high. However, the results are weaker for precious metals - the variability of the interest-adjusted spread does not appear to change when inventory is either high or low; the variability spot prices is not always greater than that of futures prices when inventory is low; and spot price changes seem to explain as much of the changes in futures prices when inventory is high as when it is low.

Another paper that tests the theory of storage on metals from September 1986 to September 1992, written by Ng and Pirrong (1994), shows that the results for industrial metals are consistent with the theory. Therefore, the spot and futures return dynamics are related to changes in demand-and-supply conditions. The results for silver, however, are much weaker than those of the industrial metals.

Geman and Ohana (2009) test the theory of storage with respect to oil and natural gas using monthly data from January 1993 to August 2008. They also test whether the interest-adjusted spread is a good proxy for inventory. They find, in accordance with theory, that there is a negative relationship between spot price volatility and inventory in the crude oil market over their sample period. The authors also find that a negative correlation exists for natural gas only during periods of scarcity - where the inventory levels are below the historical average levels - and that it increases substantially during winter periods. Lastly, they find that the interest-adjusted spread is, in fact, a good proxy for inventory.

Kroner, Kneafsey and Claessens (1993) compare various methods for forecasting the price volatility of a range of commodities - cocoa, corn, gold, wheat, cotton, silver and sugar. When looking at models that only use time series data and models that forecast only market expectations derived from option prices, the time series models tend to outperform on an overall basis. The GARCH models that were used to forecast the volatility over small periods are found to be relatively stable.

Manfredo, Leuthold and Irwin (1999) also look at the performance of several specifications when it comes to forecasting the volatility of commodity prices. These specifications include historical averages, naïve forecasts, GARCH-t models, exponentially weighted moving averages, implied volatility models and composite forecasts. The GARCH-t models, which use the Student's t-distribution to describe the conditional distribution of the returns, perform very well and show improved accuracy over other individual forecasts for short horizons.

3 Theoretical explanation of tests performed

3.1 The augmented Dickey-Fuller test

In the models that are estimated below, it is necessary for the series in the regression to be stationary. The reason for this is to eliminate the possibility of spurious regression and drawing meaningless conclusions (Yule 1926). Whether a series is stationary will depend upon whether it has a unit root - a stationary series will have no unit roots and is said to be integrated of order 0. If the series is non-stationary, it should be appropriately differenced until it is stationary, where the number of times it is differenced will depend upon the number of unit roots in the series (Ekanayake 1999, p. 45). For example, if there are 2 unit roots, the series will have to be differenced twice to render it stationary.

To test for the presence unit roots, the augmented Dickey-Fuller (ADF) test is performed. This test has a null hypothesis that the series contains a unit root (and is non-stationary), against the alternative that the series does not contain a unit root (and is stationary). Although there are other tests with the same null and alternative hypotheses, for example the Phillips-Perron test, these tend to be more complicated and difficult to use in practice (Harris 1995, p. 33-34).

The ADF test can be applied to any series that follows an autoregressive (AR) process - i.e. a series that depends upon past values of itself (cf. Tsay 2005, p. 32-40 for further explanations). Suppose the series y_t follows an AR process of order p . Dickey and Fuller (1979) consider three types of regressions to test y_t for the presence of unit roots:

$$\Delta y_t = \gamma y_{t-1} + \sum_{i=1}^p \beta_i y_{t-i+1} + \varepsilon_t \quad (3)$$

$$\Delta y_t = a_0 + \gamma y_{t-1} + \sum_{i=1}^p \beta_i y_{t-i+1} + \varepsilon_t \quad (4)$$

$$\Delta y_t = a_0 + a_1 t + \gamma y_{t-1} + \sum_{i=1}^p \beta_i y_{t-i+1} + \varepsilon_t \quad (5)$$

where:

β_i is the i^{th} lag coefficient; and

ε_t is the error term.

The first regression equation is a pure random walk model, the second adds an intercept (a_0) and the third includes both an intercept (a_0) and a time trend ($a_1 t$). In each regression, the parameter of interest is γ . If γ is zero, then the series, y_t , contains a unit root. If, however, γ is significantly different from zero, the series does not contain a unit root and is therefore stationary.

The decision of whether to include an intercept and/or time trend in the ADF test will depend upon whether the underlying series, y_t , contains these components. The use of equation 3 is only valid when the overall mean of the series is 0. If, however, the ‘true’ mean is known, it may be subtracted from each observation in the series and equation 3 can then still be used to test for the presence of a unit root (Harris 1995, p. 29). The use of equation 3 also assumes that the initial value of the series, y_0 , is equal to 0. If the true value of y_0 is unknown, it may be better to include an intercept in the regression equation - i.e. use equation 4, rather than equation 3. If y_t is a stationary process that contains a deterministic trend, using equation 4 to test for the presence of a unit root may lead to incorrect conclusions as the results may show that y_t is non-stationary. As Harris (1995, p. 30) explains, it is necessary to include as many deterministic regressors as there are deterministic components in the series when testing for the presence of a unit root. Therefore, if y_t has a deterministic trend component, equation 5 must be used.

The above regressions - equations 3, 4, and 5 - are estimated by ordinary least squares and the significance of γ is tested. Since the assumption of normality is not fulfilled, the normal t-statistic tests cannot be used. In fact, the distribution of γ is negatively skewed and would therefore lead to a large number of negative values when compared to the Student’s t-distribution (Schwert 1989, p. 147). The t-statistics of γ are therefore compared to the values given by MacKinnon (1990) to determine whether γ is significantly different from zero. These critical values depend upon whether an intercept or a time trend is included in the regression, as well as on the sample size of the series.

Some difficulties may arise when performing the ADF tests. For example, choosing the correct form and the appropriate number of lags may be problematic since using different forms or number of lags often leads to different results (Harris 1995, p. 39). Blough (1992) (cited in Harris 1995, p. 39), explains that too many lags will decrease the size of the test so that there is a high probability of falsely rejecting the null hypothesis of non-stationarity when the series is a near stationary process. If there are too few lags, however, the null hypothesis will be rejected too often, decreasing the power of the test (Harris 1995, p. 39-40).

3.2 The Spearman rank test

Fritz (1974, p. 210) and Geman and Ohana (2009, p. 582) explain the procedure of the Spearman rank test. This test is used to determine the correlation between two variables, where the null hypothesis is that there is no correlation and the alternative is that there is either a positive or a negative correlation. Suppose there are n pairs of observations (x_i, y_i) where the x_i observations are ranked serially in descending order. The highest x value is given the rank n , the second largest x value is assigned a rank $n - 1$ and so on, with the smallest x value allocated the rank 1. The values of y_i are then ranked in descending order and assigned ranks in the same manner as the x_i values. If two or more (x_i) or (y_i) have the same values,

then the rank allocated to the tied values is the mean of the ranks that would have been given to those observations if no tie had occurred. For example, suppose there are 3 y_i observations with the same value and these observations are assigned ranks of 4, 5 and 6 if no tie had occurred. The rank then actually assigned to these observations will be $(4 + 5 + 6)/3 = 5$.

Once the ranks have been allocated, d_i , the difference between the ranks of y_i and x_i , is found for each pair (x_i, y_i) . The Spearman rank correlation coefficient, r_s , is then calculated using:

$$r_s = 1 - \frac{6 \sum_{i=1}^n d_i^2}{n(n^2 - 1)} \quad (6)$$

For large samples, r_s is normally distributed with mean 0 and variance $1/(n - 1)$.

3.3 GARCH models

Engle (1982) was the first to provide a framework for volatility modelling when he introduced the Autoregressive Conditional Heteroscedastic (ARCH) model. This model allows the conditional variance to evolve over time while keeping the unconditional variance constant. If a_t is said to be modelled by an ARCH(p) model, then:

$$a_t = \sigma_t \varepsilon_t \quad (7)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 a_{t-1}^2 + \dots + \alpha_p a_{t-p}^2 \quad (8)$$

where:

$\{\varepsilon_t\}$ is a sequence of independent and identically distributed (i.i.d.) random variables with mean 0 and variance 1; and

$\alpha_0 > 0$ and $0 \leq \alpha_i < 1$ for all $i > 0$.

The two restrictions on the coefficients α_i ensure that the unconditional variance of a_t is finite and stationary. It is often assumed that ε_t follows a normal distribution.

Even though the ARCH model is fairly simple to use, it often needs a large number of parameters to be estimated from the data to sufficiently describe the volatility process (Tsay 2005, p. 113). In light of this, Bollerslev (1986) extended the ARCH model to the Generalised ARCH (GARCH) model.

If a_t is said to follow a GARCH(p,q) model, then:

$$a_t = \sigma_t \varepsilon_t \quad (9)$$

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^p \alpha_i a_{t-i}^2 + \sum_{j=1}^q \beta_j \sigma_{t-j}^2 \quad (10)$$

where:

$\{\varepsilon_t\}$ is a sequence of i.i.d. random variables with mean 0 and variance 1; and $\alpha_0 > 0$, $\alpha_i \geq 0$, $\beta_j \geq 0$, and $\sum_{i=1}^{\max(p,q)} (\alpha_i + \beta_i) < 1$.

The last constraint means that σ_t^2 , the conditional variance of a_t , changes over time, while the other restrictions ensure that its unconditional variance is finite (Tsay 2005, p. 114). Lamoureux and Lastrapes (1990, p. 225-226) show that $\sum_{i=1}^{\max(p,q)} (\alpha_i + \beta_i)$ is, in fact, a persistence term. This indicates the relationship between past and current volatility - the closer the persistence term is to one, the more past shocks have an effect on current shocks.

From the model given in equation 10, it is easy to see that large past squared shocks, $\{\sigma_{t-j}^2\}_{j=1}^q$, will result in a large conditional variance of a_t . This indicates that large past values of $\{\sigma_{t-j}^2\}_{j=1}^q$ will lead to large values of σ_t^2 , producing the behaviour of volatility clustering, which is common in financial time series (Tsay 2005, p. 114).

Forecasts of GARCH models are relatively simple to obtain. Consider the following, taken from Tsay (2005, p. 115):

Suppose we have a GARCH(1,1) model:

$$a_t = \sigma_t \varepsilon_t \quad (11)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 a_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \quad (12)$$

where $\alpha_1 > 0$, $\beta_1 < 1$, $(\alpha_1 + \beta_1) < 1$.

Assume that the forecast origin is n . The 1-step ahead forecast will be:

$$\hat{\sigma}_{n+1}^2 = \alpha_0 + \alpha_1 a_n^2 + \beta_1 \sigma_n^2 \quad (13)$$

where a_n^2 and σ_n^2 are known at time n .

For forecasts more than 1-step ahead, equation 11 is used to manipulate equation 12, so that it can be rewritten as:

$$\sigma_{t+1}^2 = \alpha_0 + (\alpha_1 + \beta_1) \sigma_t^2 + \alpha_1 \sigma_t^2 (\varepsilon_t^2 - 1) \quad (14)$$

At time $n + 1$, equation 14 becomes:

$$\sigma_{n+2}^2 = \alpha_0 + (\alpha_1 + \beta_1)\sigma_{n+1}^2 + \alpha_1\sigma_{n+1}^2(\varepsilon_{n+1}^2 - 1) \quad (15)$$

It is known that $E[\varepsilon_{n+1}^2 - 1|F_n] = 0$ from the properties of $\{\varepsilon_t\}$, where F_n contains all information of the series up to time n . Therefore, by taking expectations of both sides of equation 15, the 2-step ahead forecast must satisfy:

$$\hat{\sigma}_{n+2}^2 = \alpha_0 + (\alpha_1 + \beta_1)\hat{\sigma}_{n+1}^2$$

The general m -step ahead forecast satisfies:

$$\hat{\sigma}_{n+m}^2 = \alpha_0 + (\alpha_1 + \beta_1)\hat{\sigma}_{n+m-1}^2 \quad (16)$$

As Hull (2006, p. 472) explains, this is a weighted average of the unconditional variance of a_t ($\frac{\alpha_0}{1-\alpha_1-\beta_1}$) and the last estimate of the variance ($\hat{\sigma}_{n+m-1}^2$), provided $(\alpha_1 + \beta_1) < 1$.

By repeated substitutions into equation 16, the m -step ahead forecast is found to be:

$$\hat{\sigma}_{n+m}^2 = \frac{\alpha_0[1 - (\alpha_1 + \beta_1)^{m-1}]}{1 - \alpha_1 - \beta_1} + (\alpha_1 + \beta_1)^{m-1}\hat{\sigma}_{n+1}^2$$

where $\hat{\sigma}_{n+1}^2$ is found by equation 13.

Tsay (2005, p.114) goes on to show that:

$$\hat{\sigma}_{n+m}^2 \rightarrow \frac{\alpha_0}{1 - \alpha_1 - \beta_1}$$

as $m \rightarrow \infty$ if $(\alpha_1 + \beta_1) < 1$. Therefore, the m -step ahead volatility forecast tends towards the unconditional, or long-term average, variance of a_t provided it exists. This also indicates that if the variance at time n is greater than the long-term average variance, the variance will be expected to decrease towards this long-term average, and vice versa. In other words, the variance in mean-reverting, with a reversion level of $\frac{\alpha_0}{1-\alpha_1-\beta_1}$ and a reversion rate of $1 - \alpha_1 - \beta_1$ (Hull 2006, p. 472-473).

Past literature has shown that the GARCH(1,1) specification is found to be the best among other, more complex variations of GARCH (cf. Manfredo, Leuthold & Irwin 1999, p. 260). It has also been found that distribution of commodity returns exhibits leptokurtosis (and the returns are therefore not conditionally normally distributed) (M^cKenzie, Thomsen & Dixon 2004, p. 539); as is the case here, with a kurtosis of over 5.082 and a Jarque-Bera test statistic² of over 11.647. In order to counteract this, Bollerslev (1987) used the Student's t -distribution in the GARCH model, and named it the GARCH- t model. The only difference between the GARCH- t model and the original GARCH model is that the sequence $\{\varepsilon_t\}$ will follow a Student's t -distribution with mean 0, variance σ^2 and ν degrees of freedom (M^cKenzie, Thomsen & Dixon

²Under the null hypothesis of a normal distribution, the Jarque-Bera test has a χ^2 distribution with 2 degrees of freedom.

2004, p. 539). Taking these past findings into consideration, the GARCH-t(1,1) model is used in the subsequent analysis and forecasting purposes.

GARCH models also have some shortfalls, which will affect the forecasting performance. For example, Tsay (2005, p. 116) explains that the GARCH model assumes that volatility has the same response to both negative and positive shocks even though this is unlikely to occur in practice. As the theory of storage predicts, positive price shocks (which usually indicate a decrease in inventories) are likely to affect the spot price volatility more than negative price shocks (Carpantier 2010). Another downfall of GARCH models is that they are unable to give any further insight into what causes changes in volatility - it is merely a mechanical way of describing the volatility path. Ramchand and Susmel (1998, p. 401) explain that standard GARCH models are unable to explain any structural shifts in the data that are caused by low probability events, such as market crashes, nor are they able to capture changes in the level of unconditional variance.

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4 An outline of the movement of platinum prices from January 1992 to January 2010

Figure 3a below shows the movements of last-maturing futures prices, as well as the first near-by futures prices³, from January 1992 to January 2010. Figure 3b shows the last-maturing futures price volatility and the first near-by futures price volatility during this time period. It is clear to see that when there are large changes in the last-maturing and first near-by futures prices, there is an increase in their respective volatilities.

During the first two years of the sample period - 1992 and 1993 - the movements in platinum prices can be largely explained by an economic recession occurring in major economies during the early 1990s. This recession, which began in 1990 and continued until 1993 (Geroski, Gregg & Desjonqueres 1995, p. 35), is thought to have been caused by the Gulf War (Hall 1993, p. 279) which led to an increase in oil prices, a decrease in automobile sales and a drop in the demand for platinum (Hilliard 1998, p. 6 of 10).

The sudden increase in the futures and spot price volatility during September 1992 was a result of the events of "Black Wednesday" on 16 September 1992, when Britain left the Exchange Rate Mechanism - a system for pegging the pound and other European currencies to the German mark (Rose 1993, p. 419 & 425). This saw a sudden decrease in investor confidence and a considerable weakening of the British pound (Gavin & Sanders 1997, p. 632); as well as a decrease in the price of platinum.

The decrease in platinum prices during 1995 can be explained by the shift away from the use of platinum in catalyst converters in the automotive industry to manufacturing cheaper converters from palladium (Gooding 1995, p. 25). However, platinum prices were quick to recover and they began to increase towards the end of 1995 as a result of various problems in the South African mining industry (Reese 1996, p. 2 of 2). These sudden changes in the platinum price caused an increase in the volatility of both futures and spot prices.

The volatility of the platinum prices appears to increase from mid-1997 to 1999. Between 1997 and 1998, the demand for platinum, particularly as a jewellery metal, began to increase. In fact, it increased by 270 000 ounces (Matthey 1999) and caused the price of the precious metal to rise between July 1997 and September 1998. The sharp decline in prices during October 1998 was due to a sudden decrease in the US interest rates and a substantial weakening of the US dollar. (Sundaram 2007, p. 26).

The steady increase in platinum prices between the beginning of 2000 and the end of 2001 was due to an increase in demand across all uses of platinum, with its use in the manufacture of jewellery and autocatalysts reaching an all-time high during this period (Matthey 2000, p. 11-12 of 28). Platinum prices decreased suddenly, while volatility rose quickly towards the end of 2001, with prices falling by approximately 97 US dollars between August 2001 and September

³The prices of the first-expiring futures.

2001, after the terrorist attacks in the United States of America during 2001. Indeed, these terrorist strikes on 11 September, also referred to as the "9/11" attacks, affected economies across the world. Investor confidence decreased substantially, and as people started disinvesting in commodities and stocks, the price of platinum began to fall. The global economy started to recover throughout 2003 and beginning of 2004 (Mboweni 2004). This explains the steady rise in platinum prices during this time.

Matthey (2006, p. 1 of 3) explains that the slight increase in volatility around mid-2006 was due to the unexpectedly high consumption figures for materials and commodities in the United States of America. This, along with a stronger dollar, caused a decrease in prices - but the recovery was quick and corresponded with an announcement from Implats that production had been less than expected (Matthey 2006, p. 1 of 3).

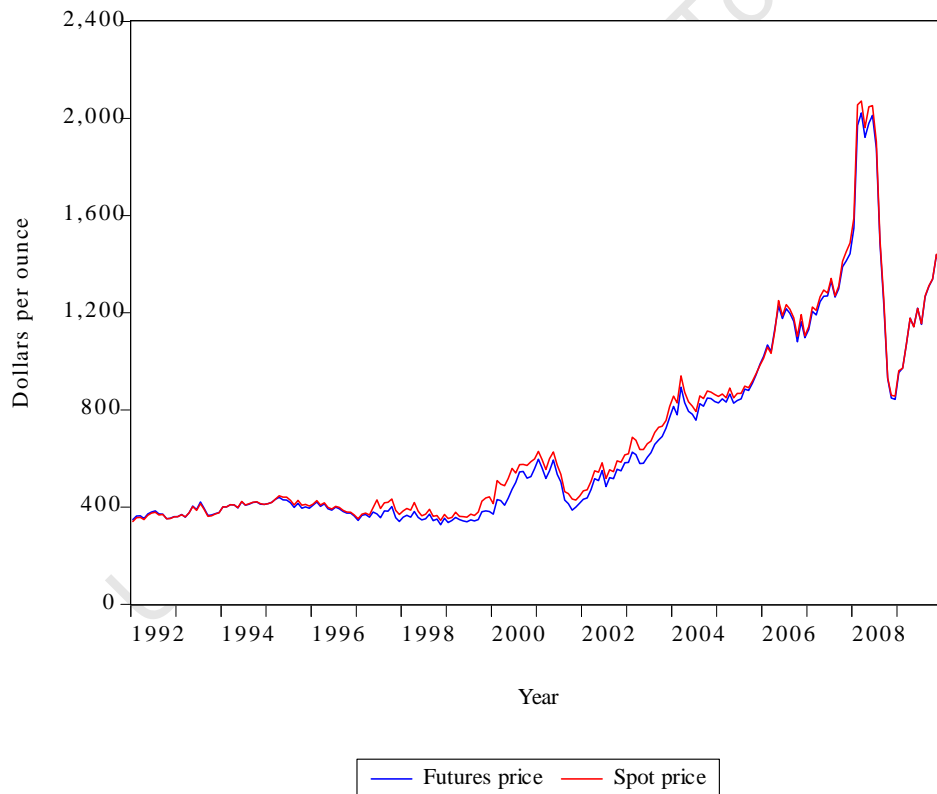


Figure 3a: The last-maturing futures (futures) prices and the first near-by futures (spot) prices

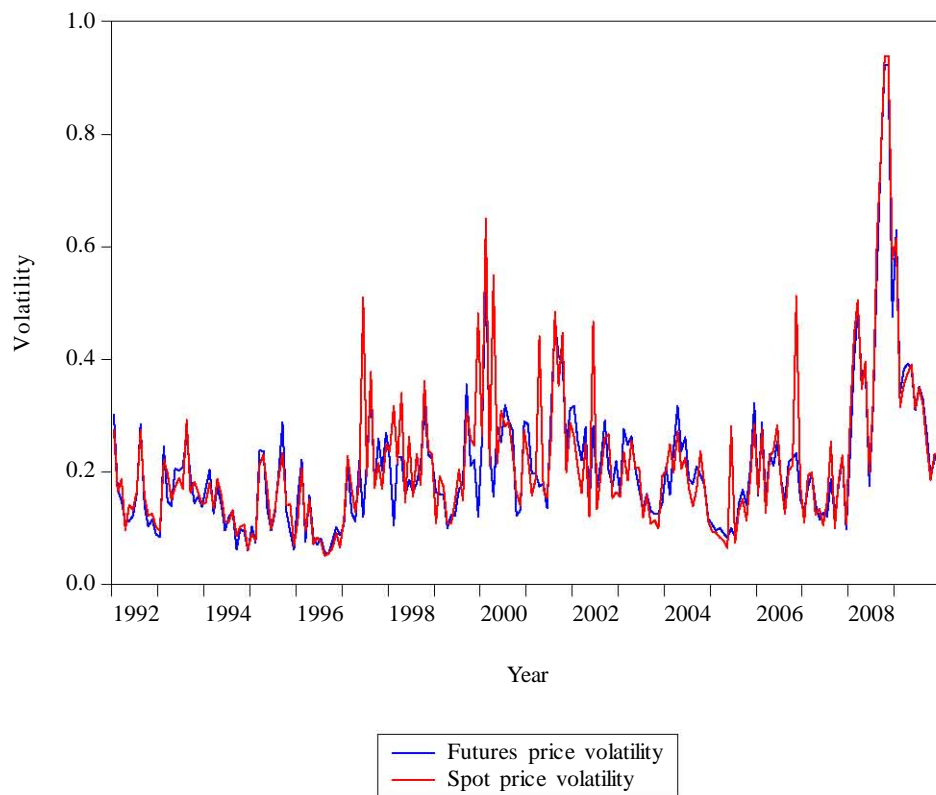


Figure 3b: The last-maturing futures (futures) price volatility and the first near-by futures (spot) price volatility

During November 2006, there were rumours of a platinum exchange traded fund (ETF) coming to the major markets (Yang 2009, p. 1807). This resulted in a large increase in platinum prices - over 97 US dollars - since there was an increase in demand as well as speculation that some platinum, which would be used to back the ETFs, would no longer be used for industrial applications.

The large increase in prices from July 2007 to July 2008 was brought about by a number of factors. During this time, the demand for direct platinum investment increased as ETFs were listed on the London Stock Exchange and the Swiss Exchange during 2007 (Yang 2009, p. 1087). This, together with the weak dollar and the high gold and oil prices, resulted in the increase in platinum prices (Matthey 2007, p. 1 of 4). During the beginning of 2008, South African mines were forced to close temporarily due to power shortages, with threats of more power outages in the near future (Matthey 2008a, p. 1 of 4; Matthey 2008b, p. 1 of 4). This led to further platinum price hikes as well as an increase in volatility.

As can be seen in figure 3a above, platinum prices decreased by over 1125 US dollars between

July 2008 and October 2008. Figure 3b shows the sudden increase in both futures and spot price volatility during this time. These movements were due to the "credit crunch", which led to a global economic recession. As investor confidence fell, people started selling their commodities and buying safer assets instead, which led to a fall in platinum prices (Matthey 2008c, p. 1 of 5). The automotive industry was also badly hit by this recession resulting in a decrease in demand for platinum and a further decrease in prices (Matthey 2009b, p.46 of 57).

Platinum prices managed to make a fairly quick recovery from the market crash and prices started to increase by the very end of 2008. This was a result of increased physical demand, particularly in Asia, as well as a sense of optimism generated by the bailout of General Motors and Chrysler by the government of the United States of America (Matthey 2008d, p. 1 of 5).

The high level of volatility around mid-2009 was due to various factors. The possible launch of ETFs in North America and South Africa caused an increase in platinum prices during the beginning of April 2009. Towards the end of April, however, platinum prices began to decrease again due to concerns surrounding the automotive industry (Matthey 2009c, p. 1 of 5). The threat of more disruptions to South African supplies led to a boost in platinum prices during June 2009 (Matthey 2009d, p. 1 of 5); but the strong dollar led to a decrease in prices during July 2009 (Matthey 2009e, p. 1 of 5). Throughout the latter half of 2009 there were further worries over supply disruptions in South Africa. This, together with an improved outlook for the automotive industry, led to an increase in prices once more (Matthey 2009f, p. 1 of 5).

Matthey (2010, p. 29) explains that the steady rise in platinum prices during January 2010 was because of the launch of a US-based ETF as well as another Swiss-based ETF, which led to significant trading during the first half of January. Strong physical demand, particularly in Asia, further increased the prices during the latter half of the month and pushed platinum to its highest level in over 18 months (Matthey 2010, p. 29).

5 Data and methodology

The price data consist of daily observations of standard platinum futures prices from the Tokyo Commodities Exchange over the period January 1992 to January 2010. The maturities used are the front month and last month contracts. When calculating the interest-adjusted spread, as shown in equation 2, the front month futures prices are used in place of the spot prices as it is the futures curve that is being modelled, rather than the spot curve. In other words, the interest-rate spread is equal to:

$$\frac{Futures_{last} - Futures_{front}[1 + R(t, T)(T - t)]}{Futures_{front}} \quad (17)$$

where:

$R(t, T)$ is the London Interbank Offered Rate (LIBOR); and

$T - t$ is determined on a 30/360 basis for ease of calculation.

The interest-adjusted spread in month x is calculated as the average daily interest-adjusted spread in that month. The monthly spot and futures log returns are also calculated in the same manner. The monthly interest-adjusted spread is detrended to remove the dependency on the particular interest rate that is used.

Although the theory of storage describes a relationship between inventory, spot prices and futures prices, reliable inventory data are difficult to find. This is because platinum is produced and consumed in a number of countries. To overcome this problem, Fama and French (1987) suggest that the sign of the detrended interest-adjusted spread can be used as a proxy for inventory, where a positive interest-adjusted spread indicates high inventory levels, and vice versa. I have used this proxy throughout the report because the interest-adjusted spread, in contrast to inventories, is easily observable.

After deriving the detrended interest-adjusted spread, I begin exploiting the implications of the theory of storage by testing relative variability of this spread. I also test the relative variability of the spot and futures log returns. I then regress the percentage changes in futures prices on the percentage changes in spot prices to determine the extent to which spot prices affect futures prices. I perform Spearman rank tests on: i) the percentage changes in futures prices and the percentage changes in spot prices, and ii) the variability of spot prices and interest-adjusted spread to establish whether these correlations are in line with what the theory predicts. All of the tests mentioned here are conducted on two sub-periods: where the interest-adjusted spread is negative ("negative periods"); and where the interest-adjusted spread is positive ("positive periods") - and over the entire sample period.

Lastly, I fit a GARCH-t(1,1) model to the spot price volatility and ascertain how easily and accurately the volatility can be forecast.

6 Empirical evidence

6.1 The detrended interest-adjusted spread

In order to detrend the interest-adjusted spread, I regress it on a constant, time and time squared. The following decomposition is obtained with the t-statistics shown under each estimated coefficient:

$$spread_t = \underset{-6.0863}{-0.0344} - \underset{-13.0860}{0.0016t} + \underset{14.5642}{(7.75 * 10^{-6})t^2} + \widetilde{spread}_t \quad (18)$$

where:

t refers to the time in months;

$spread_t$ is the interest-adjusted spread at time t ; and

\widetilde{spread}_t is the detrended interest-adjusted spread.

Although many other regressions were tried⁴, this regression is found to be the best based on the Akaike information criterion (AIC). The AIC value for this regression is -4.335. The interest-adjusted spread together with the detrended interest-adjusted spread is given in figure 4 below.

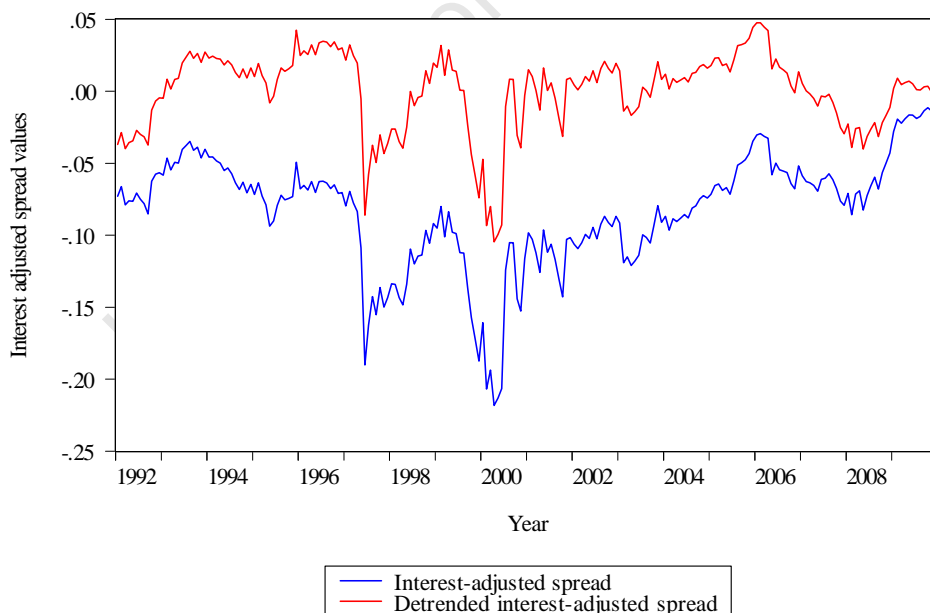


Figure 4: The detrended interest-adjusted spread and the interest-adjusted spread

⁴Other decompositions include the use of trigonometric functions as well as time values of higher and lower orders of magnitude.

6.2 The variability of the detrended interest-adjusted spread

The theory of storage predicts that the interest-adjusted spread should be less volatile when it is positive - i.e. when inventories are high, and vice versa. This is confirmed by the results of an F-test on the monthly values of the detrended interest-adjusted spread, as shown in Table 1 below.

Table 1: The results of the variability of the detrended interest-adjusted spread

	Annualised variance	F-statistic (negative/positive)
Negative periods	7.127	4.788**
Positive periods	1.488	
All periods	9.000	

** Significant at the 1% level

Note: All annualised variance figures have been multiplied by 10^3 for ease of comparison.

Table 1 gives the annualised variance during the periods where the detrended interest-adjusted spread is negative and positive as well as for the whole sample period. The F-test (cf. Fogler & Ganapathy 1982, p. 146-147 for a detailed discussion) has a null hypothesis that the variance of the interest-adjusted spread is the same during positive and negative periods against an alternative that the variance during negative periods is greater than that during positive periods. As can be seen, the F-statistic is much greater than the 1% critical value, and so it is safe to conclude that the variance over the negative periods is much larger than the variance over the periods for which the interest-adjusted spread is positive.

6.3 The variability of futures and spot returns

As implied by the theory of storage, the spot return variability should be greater than the futures return variability when the interest-adjusted spread is negative (inventory is low). However, when the interest-adjusted spread is positive (inventory is high), the variability of the spot and futures returns should be more or less the same.

The annualised variances of the spot and futures monthly log returns are used for determining whether the variability of the two are the same during periods where the interest-adjusted spread is positive, where it is negative, and over the whole sample period. Table 2 below shows the results of the F-tests, where the null is that the variances are the same and the alternative is that the spot return variance is greater than the futures return variance.

Table 2: The results of the relative variability of futures and spot returns

	Annualised variance		F-statistics
	Futures returns	Spot returns	
Negative periods	2.078	2.090	1.006
Positive periods	0.824	0.844	1.024
All periods	1.292	1.308	1.013

Note: All annualised variance figures have been multiplied by 10^4 for ease of comparison.

As can be seen, the F-statistics are not significant for any of the periods; thus, I do not reject the null indicating that the variances are the same across the entire sample period, as well as the sub-sample periods. This means that changes in demand-and-supply conditions have very similar effects on the futures and spot returns, irrespective of the level of inventory.

6.4 The effect of spot prices on futures prices

To test the extent to which futures prices respond to changes in spot prices, consider the following regression put forward by Fama and French (1988):

$$\ln[F(t, T)/F(t - 1, T)] = \alpha + \beta \ln[S(t)/S(t - 1)] + \epsilon(t) \quad (19)$$

When inventory is high (interest-adjusted spread is positive), β should be close to one as the movements of futures prices are expected to be very similar to movements in spot prices. However, when inventory is low (interest-adjusted spread is negative), β should be less than one as the changes in spot prices is expected to be greater than those of futures prices.

Before running the above regression, the percentage changes in futures prices and in spot prices are tested for stationarity with the use of the augmented Dickey-Fuller test. The number of lags used for each of the ADF tests (which are allowed to range between 1 and 12) are decided upon based on the lowest AIC value. The results of these tests are shown below and indicate that, in all periods, the percentage changes in futures prices and in spot prices do not contain a unit root. This implies that regressions may be run without the problem of potential spurious regression (Yule 1926).

Table 3: The augmented Dickey-Fuller test results

	Changes in futures prices	Changes in spot prices
Negative periods	-5.141**	-5.232**
Positive periods	-8.416**	-8.875**
All periods	-8.654**	-8.851**

** Significant at the 1% level

The results from the above regression, as given in equation 19, are shown in Table 4 below. As can be seen, the results are not always consistent with the predictions of the theory of storage. The slope coefficients are not statistically different from one at the 5% and 10% level for any of the periods tested. This is in line with the result from the previous subsection - the variability of the futures and spot returns is the same for the entire sample period as well as for the sub-periods.

Although the R^2 does decrease somewhat when comparing the positive and negative periods, it is not by any substantial figure. Thus, there is no reason to believe that the changes in spot prices explain less of the changes in futures prices when the interest-adjusted spread is negative than when it is positive.

Table 4: The results from the regression of percentage changes in futures prices on percentage changes in spot prices

	$\hat{\alpha}$	$\hat{\beta}$	s.e. ($\hat{\beta}$)	R^2
Negative periods	0.0005	0.974	0.027	0.944
Positive periods	-0.0003	0.986	0.020	0.949
All periods	-0.0001	0.979	0.016	0.946

6.5 The Spearman rank tests

As explained above, the theory of storage suggests that, when inventory is high and the interest-adjusted spread is positive, the changes in spot and in futures prices should be highly positively correlated. As inventory and the interest-adjusted spread decrease, so should the correlation between changes in spot and in futures prices. In order to test the correlation between the changes in spot and in futures prices, the Spearman rank test is carried out on the monthly futures and spot log returns.

Table 5: The results from the Spearman rank test between percentage changes in futures and in spot prices

	Spearman rank test statistic
Negative periods	0.940**
Positive periods	0.971**
All periods	0.960**

** Significant at the 1% level

The table above shows the results from the Spearman rank test. As can be seen, there is a significant positive correlation between the percentage changes in futures prices and in

spot prices during all periods and sub-periods, although this appears to decrease somewhat as inventory declines.

The theory of storage also implies that the volatility of the spot prices should increase as inventory decreases - i.e. there should be a negative relationship between the two variables. The table below shows the correlation between the annualised volatility of the spot prices and the detrended interest-adjusted spread.

The volatility of the spot prices for month x is calculated as the annualised standard deviation of the daily spot log returns in that month. The reason for calculating it in this way is because the Spearman rank test requires there to be an equal number of observations of the spot price volatility and the detrended interest-adjusted spread. This technique is also used in Geman and Ohana (2009).

As can be seen, there is a significant negative correlation during the over-all sample period; as well as when interest-adjusted spread is positive and when it is negative. The results also indicate that the correlation increases during positive periods.

Table 6: The results from the Spearman rank test between the volatility of spot prices and the detrended interest-adjusted spread

	Spearman rank test statistic
Negative periods	-0.256**
Positive periods	-0.413**
All periods	-0.447**

** Significant at the 1% level

6.6 GARCH models

As previously explained, the theory of storage indicates that commodity spot price volatility varies over time. Spot price volatility plays a key role in investment decisions - too much risk, or volatility, might cause an investor or hedger to not invest in that particular asset. If, however, the volatility can be modelled and forecast accurately, investors may be more willing to increase their exposure to that asset.

These two factors motivate the use of GARCH-type models to model and forecast the spot price volatility in the platinum market. As explained above, the GARCH-t(1,1) specification appears to be the best, based on past literature.

I examine the 6, 12 and 24 month forecast performance of a GARCH-t(1,1) model fitted to the monthly percentage changes in spot prices for various sample periods. The initial period for which I fit a GARCH-t(1,1) model covers the ten year interval between January 1992 and December 2001. The next ten year period runs from January 1993 to December 2002. I continue in this fashion, with the last ten year period starting in January 1998 and ending in December

2007. I then increase the sample period to eleven years, with the first period running from January 1992 until December 2002; and the second period running from January 1993 until December 2003. I continue in the same manner until the last eleven year stretch (January 1997 to December 2007) before increasing the sample period to twelve years and continuing in this pattern until I have achieved a sixteen year sample period - January 1992 to December 2007. Each model is forecast for 6, 12 and 24 months. The Mean Square Error (MSE) of these models is compared to find the best performing model in terms of forecasting abilities.

Table 7: An example of a GARCH-t(1,1) model

	Estimate	Standard error
c	$6.55*10^{-7}$	$8.38*10^{-7}$
α	0.065	0.061
β	0.842	0.153

Table 7 above shows the coefficients from the GARCH-t(1,1) model for the 15 year period starting in 1993 and ending in 2007. Each sample period analysed uses a different GARCH-t(1,1) model. In other words, the seven 10 year sample periods, the six 11 year sample periods, and so on, each have a different GARCH-t(1,1) model, resulting in 28 models. However, all the models are very similar, and so only one is shown here.

As can be seen, the sum of the ARCH and GARCH coefficients ($\alpha + \beta$) is very close to one, indicating that volatility shocks are quite persistent, as is common in financial time series data. The ARCH coefficient and the constant coefficient, however, are not significantly different from 0, and should perhaps be excluded. So as not to potentially lose information and to keep consistency between the models, the coefficients have remained in the model.

Table 8: The GARCH-t(1,1) forecast results

Forecast model	MSE	Sample period	Prediction period
Best	0.791	01/1997 - 12/2006	01/2007 - 06/2007
Worst	281.464	01/1993 - 12/2007	01/2008 - 12/2008

Note: i) All MSE figures presented in this table have been multiplied by 10^8 for ease of comparison.
 ii) The dates are in the form of mm/yyyy.

The table above shows the overall best and worst models from the evaluation of the forecast performance of the GARCH-t(1,1) models. As can be seen, the overall worst forecast period is during 2008. This is a year characterised by a steady climb in prices during the first few months of the year and a market crash occurring during the latter half of the year. The poor forecasting

performance is to be expected as the prices during the six years preceding the prediction period display a long-term increasing trend and are relatively stable when compared with 2008. The GARCH-t(1,1) model will attempt to continue this pattern, resulting in poor predictions during this 12 month period.

Table 8 also indicates that the best forecast period is during a time when the platinum market is increasing steadily, and had been for most of the sample period. The GARCH-t(1,1) model is essentially a weighted average of the long-term volatility and the last predicted volatility (Hull 2006, p. 472), and will try to predict future volatility based on the trends and long-term average variance displayed in the sample period. Thus, the model is able to accurately forecast the volatility over this 6 month prediction period.

Although not all the results are shown here (see appendix for further results), when comparing the six month forecasts for the GARCH-t(1,1) models, the one with a 10 year sample period starting in 1997 is the best performing model. The worst performing model covers 15 years in the sample period ending in December 2007. This is also the case when comparing the 12 month forecasts. For the 24 month forecasts, the best performing model also has a sample period of 10 years but starts in 1994. The worst performing model for the 24 month forecasts contains 15 years in the sample period and ends in December 2007.

7 Discussions and conclusions

As explained above, the theory of storage predicts that when inventory is high (and detrended interest-adjusted spread is positive), any changes in the current demand-and-supply conditions that cause large changes in inventory will have roughly the same effect on spot and futures prices. Therefore, changes in spot prices are, for the most part, permanent, and appear one for one in futures price changes. However, when inventory is low (and the detrended interest-adjusted spread is negative), changes in the current demand-and-supply conditions will cause a small change in inventory. This will result in the changes in spot prices being greater than the changes in futures prices.

The results above show that empirical evidence is not always in line with theoretical predictions and the interest-adjusted spread does not explain much of the variation in platinum prices. Changes in demand-and-supply conditions appear to affect the futures and spot returns in a similar manner, irrespective of whether the inventory level is high or low. The regression results in section 6.4 indicate that changes in spot prices appear one for one in futures price changes and the Spearman rank tests show that there is a significant positive correlation between the percentage changes in futures prices and in spot prices. These results hold true irrespective of the inventory level.

A possible reason for platinum not behaving as the theory implies is that the supply curve of platinum is not as elastic as the theory assumes and therefore, even when inventory is low, futures returns are as variable as spot returns. As Yang (2009, p. 1806) explains, South Africa's poor social and political environments, as well as the lack of infrastructure, indicate that a sudden increase in supply, particularly in the near future, is not likely to occur. Another reason for the weak results is that precious metals such as platinum may be held for its value, which means that the variation of the interest-adjusted is fairly low (Ng & Pirrong 1994, p. 205). Fama and French (1988, p. 1092) explain that the relative cost of storage for precious metals, as given in equation 2, will be small. This leads to inventories being large enough to keep the relative convenience yield close to zero. Thus, the interest-adjusted spread will be high and will ensure that spot prices and futures prices have a one to one variation.

In line with what the theory predicts, the results indicate that the correlation between inventory and the annualised spot price volatility is significantly negative during times when inventory is low as well as when it is high, although the correlation appears to decrease somewhat as inventory decreases. The reason for this may be that the interest-adjusted spread is more variable when it is negative than when it is positive.

The forecast results indicate that the GARCH-t(1,1) model is able to forecast the spot price volatility of platinum over times where the price exhibits changes and trends that are somewhat similar to those during the sample period. Moreover, this prediction should only be for a very small period of time. A reason for these poor results may be due to the difficulty of comparing the

forecasting abilities of various models because the volatility of returns is not directly observable (Tsay 2005, p. 121). Perhaps more sophisticated techniques, or high frequency data (daily or weekly data, for example), would enable future volatility to be predicted with a higher degree of accuracy. This, along with trying to find any feasible trading strategies that will exploit the volatility of platinum, will be left to future research.

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9 Appendix

Table 9: The GARCH-t(1,1) forecast results for a 6 month forecast period

Sample Period: 10 Yrs	MSE	Sample Period: 13 Yrs	MSE
01/1992 - 12/2001	13.201	01/1992 - 12/2004	1.453
01/1993 - 12/2002	3.331	01/1993 - 12/2005	4.544
01/1994 - 12/2003	4.176	01/1994 - 12/2006	0.806
01/1995 - 12/2004	1.408	01/1995 - 12/2007	36.777
01/1996 - 12/2005	4.482	Sample Period: 14 Yrs	
01/1997 - 12/2006	0.791	01/1992 - 12/2005	4.531
01/1998 - 12/2007	36.689	01/1993 - 12/2006	0.812
Sample Period: 11 Yrs		01/1994 - 12/2007	36.842
01/1992 - 12/2002	3.323	Sample Period of 15 Yrs	
01/1993 - 12/2003	4.209	01/1992 - 12/2006	0.811
01/1994 - 12/2004	1.446	01/1993 - 12/2007	36.857
01/1995 - 12/2005	4.499	Sample Period of 16 Yrs	
01/1996 - 12/2006	0.794	01/1992 - 12/2006	36.841
01/1997 - 12/2007	36.679		
Sample Period: 12 Yrs			
01/1992 - 12/2003	4.195		
01/1993 - 12/2004	1.456		
01/1994 - 12/2005	4.535		
01/1995 - 12/2006	0.795		
01/1996 - 12/2007	36.763		

Note: i) All MSE figures presented in this table have been multiplied by 10^8 for ease of comparison.

ii) The dates are in the form of mm/yyyy.

Table 10: The GARCH-t(1,1) forecast results for a 12 month forecast period

Sample Period: 10 Yrs	MSE	Sample Period: 13 Yrs	MSE
01/1992 - 12/2001	7.937	01/1992 - 12/2004	6.361
01/1993 - 12/2002	1.941	01/1993 - 12/2005	6.259
01/1994 - 12/2003	2.794	01/1994 - 12/2006	141.324
01/1995 - 12/2004	1.715	01/1995 - 12/2007	156.727
01/1996 - 12/2005	10.940	Sample Period: 14 Yrs	
01/1997 - 12/2006	1.472	01/1992 - 12/2005	6.247
01/1998 - 12/2007	281.094	01/1993 - 12/2006	141.436
Sample Period: 11 Yrs		01/1994 - 12/2007	156.817
01/1992 - 12/2002	1.934	Sample Period of 15 Yrs	
01/1993 - 12/2003	2.822	01/1992 - 12/2006	141.436
01/1994 - 12/2004	1.762	01/1993 - 12/2007	156.871
01/1995 - 12/2005	10.962	Sample Period of 16 Yrs	
01/1996 - 12/2006	1.475	01/1992 - 12/2006	156.863
01/1997 - 12/2007	281.066		
Sample Period: 12 Yrs			
01/1992 - 12/2003	2.810		
01/1993 - 12/2004	1.778		
01/1994 - 12/2005	11.002		
01/1995 - 12/2006	1.475		
01/1996 - 12/2007	281.226		

Note: i) All MSE figures presented in this table have been multiplied by 10^8 for ease of comparison.

ii) The dates are in the form of mm/yyyy.

Table 11: The GARCH-t(1,1) forecast results for a 24 month forecast period

Sample Period: 10 Yrs	MSE	Sample Period: 13 Yrs	MSE
01/1992 - 12/2001	4.738	01/1992 - 12/2004	1.105
01/1993 - 12/2002	2.349	01/1993 - 12/2005	1.175
01/1994 - 12/2003	2.263	01/1994 - 12/2006	5.832
01/1995 - 12/2004	6.253	01/1995 - 12/2007	7.322
01/1996 - 12/2005	6.205	Sample Period: 14 Yrs	
01/1997 - 12/2006	141.266	01/1992 - 12/2005	1.162
01/1998 - 12/2007	156.622	01/1993 - 12/2006	5.883
Sample Period: 11 Yrs		01/1994 - 12/2007	7.367
01/1992 - 12/2002	2.336	Sample Period of 15 Yrs	
01/1993 - 12/2003	2.293	01/1992 - 12/2006	5.883
01/1994 - 12/2004	6.329	01/1993 - 12/2007	7.395
01/1995 - 12/2005	6.221	Sample Period of 16 Yrs	
01/1996 - 12/2006	141.267	01/1992 - 12/2006	7.391
01/1997 - 12/2007	156.603		
Sample Period: 12 Yrs			
01/1992 - 12/2003	2.282		
01/1993 - 12/2004	6.370		
01/1994 - 12/2005	6.244		
01/1995 - 12/2006	141.270		
01/1996 - 12/2007	156.705		

Note: i) All MSE figures presented in this table have been multiplied by 10^8 for ease of comparison.
 ii) The dates are in the form of mm/yyyy.