Alchemy in the 21st Century: Hedging with Gold Futures

Abstract

Recently, the Shanghai Futures Exchange (SHFE) introduced gold futures trading in China. This paper is the first to study the SHFE gold futures, and to evaluate the futures hedging effectiveness since the introduction. The results show that hedging with gold futures reduces the variance of a hedged gold spot position by about 88% in its first two years of existence. During the second half of 2008, however, when the global financial crisis escalated, the variance reduction dropped to about 70%. Overall, the new Chinese gold futures prove to be attractive and well-needed hedging vehicles for domestic Chinese gold producers, refiners, consumers and investors.

Key words: Gold futures; China's gold market; Hedging effectiveness

1 INTRODUCTION

Recent financial uncertainty has sparked an increasing interest in gold as an investment or portfolio insurance. The supply of financial derivatives with gold as underlying asset has grown and diversified to new products, such as exchange traded funds and mini-futures. These products have also reached geographical segments beyond the traditional hubs in London, New York and Zürich. Gold derivatives have recently emerged on financial markets in Hong Kong, Seoul, Shanghai, Singapore and Taiwan. This tilt of financial gold markets towards Asia and particularly China reflects the continent's current dominance of demand and supply of physical gold in world markets. China has the world's largest gold production and is second only to India in gold consumption.

In spite of its world leading position in terms of supply and demand, China's gold market is only emerging and has been immature in terms of financial gold products. Recently, several important steps toward an efficient gold market have been taken. The Shanghai Gold Exchange (SGE) was founded in 2002 and is now the largest spot gold exchange in the world. In 2004 a Chinese spot-deferred contract (SDC) was introduced,[1] and in 2008, the Shanghai Futures Exchange (SHFE) introduced trading in gold futures. The latter quickly has gained a dominant share among the Chinese gold products. Even though trading in gold futures at the SHFE has been in operation only for two years, and is only open to domestic investors, the contract is already the fourth most traded gold future in the world.[2] To our knowledge, no academic study has analyzed the Chinese gold futures market. The aim of this study is to fill that gap. In particular, we analyze optimal

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[1] A spot-deferred contract (SDC) is a type of rolling forward contract where delivery can be postponed.

[2] The top three gold futures are traded in U.S., India and Japan (SHFE et al., 2010).

gold futures hedging strategies and evaluate the effectiveness of the hedging strategies in the first two years of Chinese gold futures trading. The purpose is to identify whether the Chinese gold futures market provides a satisfactory avenue for gold investors, refiners, producers and other gold-related companies to hedge their risk exposures.

The interaction between spot and futures markets is important for hedging, and such aspects are explored in several gold price studies. Using monthly data for 1975-1979, Abken (1980) find that three-month gold futures prices assimilate new information efficiently, making them good predictors of future spot prices. Further studies on the efficiency of spot and futures prices are provided by Ma and Soenen (1988), Monroe and Cohn (1986), and Liu and Chou (2003). Bertus and Stanhouse (2001) point out that gold is associated with low storage costs (indefinite durability) and transaction costs (ownership changes do not usually imply physical movement of the good), is traded around the clock, and has a stable supply as there is much more gold in storage than what is being produced. Thus, the relationship between gold spot and futures prices ought to be more stable than for other commodities. Given that the relationship between spot and futures prices is well explored, there are surprisingly few studies on gold futures hedging. To our knowledge, the only paper investigating the efficiency of gold futures hedging is Baillie and Myers (1991).[3] Using US data from 1982 and 1986 on six different commodities, including gold, they show that a constant OLS hedge performs almost as well as a time-varying generalized

[3] Shalit (1995) theoretically shows that the mean extended Gini (MEG) hedge ratio converges to the minimum variance (MV) ratio when log futures prices are normally distributed. In his empirical tests, he estimates MEG and MV hedge ratios for the four COMEX metal futures including gold futures. The results show that for short-term gold contracts, the two ratios are likely to be the same. This does not hold for long-term contracts, because they are likely to have non-normal logged prices. Shalit (1995) does not discuss efficiency of gold futures hedging strategies.

autoregressive conditional heteroskedasticity (GARCH) hedge for gold futures in reducing the hedged spot portfolio variance.

This paper contributes to previous research in the following ways. Firstly, this paper is the first study of the increasingly important Chinese gold futures market and of the gold futures contracts' hedging effectiveness. Moreover, this paper also analyzes the gold futures since the introduction of gold futures trading at the SHFE. Thus, apart from being able to document the hedging effectiveness of the SHFE gold futures for the first time, this paper also provide important insights into the evolution of the hedging performance at an emerging futures market. Secondly, for gold futures hedging in general, this paper extends the analysis of Baillie and Myers (1991) by considering several alternative hedging strategies, including naïve strategy, static constant strategy, and different dynamic strategies reflecting the latest futures hedging research. In addition, we use a more comprehensive data set relative that of Baillie and Myers (1991), covering all traded gold futures contracts over a two-year period (rather than two selected contracts), which allows for a more elaborate evaluation of hedging performance across different contracts and over time. Thirdly, the sample period coincides with the global financial crisis in 2008 that led to high volatility in all asset classes, including gold. This provides an interesting test ground for how the crisis affected gold futures and hedging performance.

The results of this study show that the SHFE gold futures are well-suited for hedging spot gold products from the SGE, able to reduce the daily variance of a hedged gold spot position by almost 80% on average in its first year of existence (2008) and by almost 90% in the second year (2009). The relatively worse hedging performance during 2008 is likely to be due to the financial turmoil.

In fact, hedging performance is adequate for the first half of 2008, while clearly worse during the second half of 2008, when the global financial crisis escalated. Hence, the new Chinese gold futures proves to be an attractive and well-needed hedging vehicle for domestic Chinese gold producers and consumers (who in general are barred from international derivatives markets), immediately following the introduction.

The results also show that the returns series of both spot and futures products on the Chinese gold market are well-represented by bivariate GARCH models (with constant or dynamic correlations). However, accounting for such effects in the design of hedging strategies does not give any edge relative to the considerably simpler regression-based hedge. All these results are consistent across spot gold products and hold both in- and out-of-sample.

The following section provides an introduction to the Chinese gold market along with information on the data set applied in this study. After that, the methodology for the hedging performance evaluation is presented, followed by results and discussion. A final section concludes.

2 THE CHINESE GOLD MARKET

Gold consumers, producers and investors in China have until recently had limited hedging opportunities as only ten (state-owned) actors have been allowed access to international derivatives markets, and domestic supply of hedging venues has been scarce. This section introduces the development of the Chinese gold market, with special focus on hedging alternatives, regulations and practices. It also presents the data used for the subsequent empirical analysis.

Market structure

Deregulation and development of the Chinese gold market lags far behind developed markets. Prior to 2002, all parts of the gold market in China were strictly regulated. For example, gold prices and quotas were jointly determined by the central bank and other authorities (see Ong, 2010, for more information on China's gold market reform process). With the establishment of the SGE on October 30, 2002, the central banks gold trading regulation system was replaced by open trading activities among exchange members on the SGE. To provide hedging tools for domestic gold consumers and producers, the SGE introduced SDC's for gold in 2004. The SGE is heavily regulated with price limits, position limits, large position reporting, and forcibly close-out of positions. The exchange is open for domestic investors only, with the exception of five foreign institutional investors. Still, gold trading on the SGE has grown quickly, and the SGE is now the world's largest gold spot exchange in terms of trading volume (SHFE et al., 2010).[4] At present, trading is available in four spot gold products (*Au 50g*, *Au 100g*, *Au 99.95* and *Au 99.99*) and four gold SDC's (*Au T+5*, *Au T+D*, *Au T+N1* and *Au T+N2*)[5] via exchange members during the SGE trading hours; from 9:00 am to 11:30 am, 13:30 pm to 15:30 pm, and 21:00 pm to 2:30 am.[6]

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[4] In 2009, about 4710.82 tons of gold trading took place on the SGE with a trading volume of 1028.87 billion RMB. Institutional actors account for 90.69% of the total trading (SHFE et al., 2010).

[5] In 2004, the SDC's *Au* (*T+D*) and *Au* (*T+5*) were introduced, followed by *Au* (*T+N1*) and *Au* (*T+N2*) in 2007. The dominant contract on the SGE is *Au* (*T+D*), accounting for 94.78% of the gold SDC trading and 69.18% of all SGE gold trading in 2009. Chinese SDC's have some peculiarities. SDC buyers (sellers) can require immediate delivery as other spot products, e.g. Au 99.95, or they can choose at their own discretion how long to defer the delivery. When delivery is deferred a deferment fee is incurred. For example, the long position holder of *Au* (*T+D*) pays a daily

In response to growing domestic gold investment and hedging demand, the SHFE launched the first standardized gold futures contract on January 9, 2008. The gold futures have a monthly maturity cycle. On the 15th of each month, when the exchange is open for trading, one contract expires and a new one with time to maturity of one year is initiated. For instance, towards mid July, the July contracts expire and are replaced with newly issued July contracts with one year maturity. At the same time, contracts maturing in August (with one month left to maturity) up to June (with eleven months left to maturity) are also listed. All futures are physically settled at maturity, and marked-to-market on a daily basis. Table 1 presents detailed contract specifications for gold futures traded at the SHFE. Note that at maturity gold bullion with 99.95% purity is the cheapest to deliver, which corresponds to one of the traded spot contracts at the SGE. The SHFE gold futures are available to domestic investors only. Still, it has been popular from the start in 2008, and it is now the fourth largest gold futures contract in the world (in terms of kilograms).

Gold hedging practices

In global gold markets numerous methods for hedging exist, including forwards, gold loans, swaps, SDC's, and futures. Hedgers include producers, consumers and investors. Tufano (1996) reports that 85% of the North American gold mining firms use some form of hedging. The choice of hedging instrument is of course dependent on the type of gold price exposure to be hedged. Also, Adam (2007) finds that for gold mining firms the choice depends on the firm's financial

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deferment fee of 0.02% to the short position holder if the daily delivery supply orders exceed delivery demand orders.

[6] The evening trading session from 21:00 pm to 2:30 am was introduced in the SGE on November 8, 2005. In 2009, evening session trading accounted for 33.29% of the total daily trading.

constraint status. He also reports that the choice is related current market conditions, suggesting that managers' market views partially drive hedging instrument choices.

For the majority of the Chinese producers and consumers of gold, currently available hedging alternatives are: 1) SDC's traded on the SGE; 2) gold futures traded on the SHFE and 3) other over-the-counter products, e.g. gold forwards and gold options. Ten state-owned actors also have permission to engage in overseas futures hedging. According to SHFE et al. (2010), in 2009, futures dominated the gold derivatives market with a trading volume equivalent to 6,812 tons (about two thirds of the market). SDC's had a trading volume of 3,439 tons, whereas gold forwards and options only amounted to 51 tons. These figures clearly support the motivation to focus on gold futures in this study of hedging strategies.

We note that the trading pattern of the Chinese market deviates from that reported by Adam (2007) for North American gold miners. According to his data, covering 50 gold miners hedging activities 1989-1999, SDC's and options were the most popular hedging tools (accounting for about 40% each). No hedging with futures was reported. According to Tufano (1996), North American gold miners avoid gold futures as they might entail cash margin calls. The Chinese SDC's and gold futures are both traded in a setting requiring margin accounts, and possible margin calls. In addition, the SDC's were until 2009 open only to institutional traders.

Data

The data set in this study consists of daily spot opening, closing, high, low, volume-weighted average prices, trading volume (in kilograms and RMB) and open interest for all the spot products and SDC's, obtained from the SGE. Three of the four listed spot gold products are used in the empirical analysis, namely *Au 100g*, *Au 99.95* and *Au 99.99*, since these contracts have a positive trading volume for each day during the sample period, whereas the fourth contract, *Au 50g*, is more infrequently traded.

The daily opening, closing, high, low, volume-weighted average prices, volume, open interest, turnover, and the number of trades for all the gold futures contracts, during the same sample period, are obtained from the SHFE. The sample period ranges from January 9, 2008, corresponding to the opening date of the SHFE, to February 12, 2010, which comprises 515 trading days. The sample is divided into two sub-periods, called Period I and Period II, where Period I is between January 9, 2008, and December 31, 2008 (241 days), and Period II is between January 1, 2009, and February 12, 2010 (274 days). All prices in the data set are denoted in the local RMB currency.

3 EMPIRICAL FRAMEWORK

This section presents the models underlying the hedging strategies subject to evaluation in the empirical study, then presents various criteria for evaluating them, and finally shows details on how to estimate the models.

Hedging strategy models

An investor is assumed to hold a long gold spot holding and to hedge that holding on a daily basis using a short position in futures contracts. The number of short futures contracts required to hedge one unit long spot holding is referred to as the hedge ratio and is denoted φ. Logarithms of spot and futures gold prices at time t are denoted S_t and F_t, and returns are defined as changes in logarithms of prices. Hence, returns on spot and futures gold positions, $R_{s,t} = S_t - S_{t-1}$ and $R_{f,t} = F_t - F_{t-1}$, yield the portfolio return $R_{p,t} = R_{s,t} - \varphi R_{f,t}$. Conditioning on the information available at time $t-1$, the expected portfolio return can be written as:

(1) $$E(R_{p,t} \mid \Omega_{t-1}) = E(R_{s,t} \mid \Omega_{t-1}) - \varphi_{t-1} E(R_{f,t} \mid \Omega_{t-1})$$

where Ω_{t-1} is the set of information available at time $t-1$. The conditional portfolio variance is then:

(2) $$Var(R_{p,t} \mid \Omega_{t-1}) = Var(R_{s,t} \mid \Omega_{t-1}) + Var(R_{f,t} \mid \Omega_{t-1}) - 2\varphi_{t-1} Cov(R_{s,t}, R_{f,t} \mid \Omega_{t-1}).$$

The investor is utilizing a minimum-variance hedge strategy. Hence, the futures hedge position that minimizes the conditional variance of the portfolio returns in Eq. (2) is the optimal hedge ratio, which is given by:

(3) $$\varphi^*_{t-1} = \frac{Cov(R_{s,t}, R_{f,t} \mid \Omega_{t-1})}{Var(R_{f,t} \mid \Omega_{t-1})}.$$

Four different hedging strategies are evaluated. Firstly, the one-to-one naïve hedge is considered, which assumes that $\varphi^*_{t-1} = 1$. This strategy is optimal only if the futures contract exhibits no basis risk, e.g. if the underlying commodity of the futures contract is exactly the same as the commodity to be hedged. This model involves no estimation and is thus very simple to implement. Secondly, the regression model by Ederington (1979) is considered, in which φ^*_{t-1} is estimated using ordinary least squares on the relationship between spot and futures returns. Finally, two different strategies based on generalized autoregressive conditional heteroskedasticity (GARCH) models are considered. Several studies show that gold prices in both spot and futures markets have time-varying variances (Lucey and Tully, 2006; Tully and Lucey, 2007; Baur 2009). GARCH models account for such time-varying variances by allowing time-varying optimal hedge ratios. Several versions of GARCH models are suggested in the previous literature. In this study, both Bollerslev's (1988) constant correlation (CC) specification and Engle's (2002) dynamic conditional correlation (DCC) specification are implemented.

The evidence of time-varying volatilities in commodity prices suggests that hedging strategies accounting for such should be superior to simpler strategies. Examples of studies implementing hedging strategies based on GARCH models for various commodities are Baillie and Myers (1991, bivariate GARCH), Brooks et al. (2002, bivariate vector error-correction model asymmetric GARCH), and Lien and Yang (2008, asymmetric basis bivariate fractionally integrated GARCH). In-sample, these models yield slight improvements in hedging performance over simpler alternatives. Out-of-sample, however, the benefits of GARCH-based hedging strategies are limited (Myers, 1991), zero (Fackler and McNew, 1994), or even negative (Holmes, 1996; Chakraborty and Barkoulas, 1999). Next, the criteria for hedging strategy evaluation applied in this study are outlined.

Hedging strategy evaluation

All hedging strategy evaluation in this study is performed both in-sample and out-of-sample. For in-sample analysis, the full sample is used for both estimation and evaluation. For out-of-sample analysis the first five months are used as an initial estimation sample (January 9, 2008 – May 30, 2008). The estimation sample is used to estimate all hedging strategies' initial coefficients. Based on those coefficients, hedge ratios for the first day are calculated and out-of-sample hedging errors are recorded simply as the daily realized hedged portfolios' return $R_{p,t} = R_{s,t} - \varphi^*_{t-1} R_{f,t}$. The same procedure is applied for every subsequent day in the sample, letting the estimation window expand by one day for each step forward in time. Once the estimation procedure is iterated through the whole sample, time series hedging error variances, σ^2_{HE} , are calculated.

Two hedging performance metrics are used. Following Ederington (1979), the first metric is defined as

(4) $$HP = \left(1 - \frac{\sigma^2_{HE}}{\sigma^2_R} \right),$$

where σ^2_R is the variance of the unhedged gold spot returns. According to Kofman and McGlenchy (2005), *HP* is the most commonly used hedging performance measure. It measures the variance reduction achieved by using the futures contract relative the original unhedged gold spot variance. However, the *HP* measure only takes the variance reduction dimension of hedging into account, while ignoring the return of the hedged portfolio.

The second metric used is the utility-based criterion proposed by West et al. (2003). It is used to investigate how a hedger's utility is improved using a certain hedging strategy relative an alternative model. Suppose that the investor's expected utility from the hedged portfolio can be described as

(5) $$EU(R_p) = E(R_p) - \gamma Var(R_p),$$

Where γ is the investor's degree of risk aversion.[7] Different hedge ratios lead to different portfolio returns and, therefore, different levels of expected utility.

The in-sample and out-of-sample hedging performance is evaluated for the entire sample, and separately for Period I and Period II. Period I contains 2008, a year of considerable volatility in financial markets all over the world. This induced gold trading from investors worldwide, both as a source of liquidity when global liquidity dried up, and as a quality investment when other investments became too risky. To investigate how the crisis affected the Chinese gold market and the futures hedging performance, comparisons are made across the two periods. Period I includes the financial turmoil, but potentially also start-up effects of the SHFE. Hence, Period I is further divided into two sub-periods; Period IA, the first part of 2008 before the crisis, and Period IB, the second part of 2008, when the financial turmoil escalated, in an attempt to isolate the impact of the financial turmoil on hedging performance from any start-up effects of the newly introduced gold futures.

Hedging strategy estimation

In order to estimate the optimal hedge ratio in Eq. (3), the following general framework is applied. The gold spot returns and the futures returns are estimated in a bivariate model according to:

(6) $$R_{s,t} = \mu_s + \lambda_s B_{t-1} + \varepsilon_{s,t}$$

(7) $$R_{f,t} = \mu_f + \lambda_f B_{t-1} + \varepsilon_{f,t}$$

[7] Grossman and Shiller (1981) and Chou (1988) assume risk aversion parameters of 4 and 4.5 respectively. In this analysis $\gamma = 4.5$.

where μ_s and μ_f are intercepts, $B_{t-1} = F_{t-1} - S_{t-1}$ is the lagged basis, and $\varepsilon_{s,t}$ and $\varepsilon_{f,t}$ are error terms. This model can be seen as a vector error-correction specification, allowing for a cointegrating vector of $[1 \quad -1]$ between the logarithms of gold spot and futures prices. B_{t-1} is then the long run error-correction term. Error-correction models are used to estimate optimal hedge ratios by, among others, Brooks et al. (2002) and Lien and Yang (2008). Brenner and Kroner (1995) discuss the possibility of cointegration relationship between spot and futures prices in general, whereas Lien (1996) analyzes the effects of the cointegration relationship on minimum variance hedge ratios and hedging effectiveness.

Denoting the vector of residuals from Eq. (6) and (7) $\varepsilon_t = [\varepsilon_{s,t} \quad \varepsilon_{f,t}]'$, the conditional distribution of ε_t is assumed to be bivariate normal with the conditional variance-covariance matrix

$$(8) \qquad H_t = Var(\varepsilon_t \mid \Omega_{t-1}) = \begin{bmatrix} h_{s,t} & \rho_t \sqrt{h_{s,t} h_{f,t}} \\ \rho_t \sqrt{h_{s,t} h_{f,t}} & h_{f,t} \end{bmatrix}$$

where $h_{s,t} = Var(R_{s,t} \mid \Omega_{t-1})$, $h_{f,t} = Var(R_{f,t} \mid \Omega_{t-1})$, and ρ_t is the conditional correlation coefficient between spot and futures returns. Using this specification of the conditional variance-covariance matrix the optimal hedge ratio becomes

$$(9) \qquad \varphi_{t-1}^{*} = \rho_t \sqrt{h_{s,t} / h_{f,t}} \, .$$

In accordance with the DCC-GARCH model (Engle, 2002) and the more parsimonious CC-GARCH model (Bollerslev, 1988), the conditional variance equations are written as:

$$(10) \qquad h_{s,t} = \omega_s + \alpha_s \varepsilon_{s,t-1}^2 + \beta_s h_{s,t-1};$$

(11) $h_{f,t} = \omega_f + \alpha_f \varepsilon_{f,t-1}^2 + \beta_f h_{f,t-1}$.

Moreover, in the DCC specification, the conditional correlation coefficient is modeled as:

(12) $\rho_t = (1 - \phi_1 - \phi_2)\overline{\rho} + \phi_1 \rho_{t-1} + \phi_2 \pi_{t-1}$

where $\overline{\rho}$ is the unconditional correlation between $\varepsilon_{s,t}$ and $\varepsilon_{f,t}$, and:

(13) $$\pi_{t-1} = \frac{\sum_{h=1}^{m} \eta_{s,t-h} \eta_{f,t-h}}{\sqrt{\sum_{h=1}^{m} \eta_{s,t-h}^2 \sum_{h=1}^{m} \eta_{f,t-h}^2}}$$

for $m \geq 2$, where $\eta_{s,t-j} = \varepsilon_{s,t} / \sqrt{h_{s,t}}$, and $\eta_{f,t-j} = \varepsilon_{f,t} / \sqrt{h_{f,t}}$.

The optimal hedge ratio in Eq. (9) is conditional on the available information, and depends on the conditional variance of gold spot returns, the conditional variance of the futures returns, and the conditional correlation coefficient. Hence, in the DCC-GARCH framework, the optimal hedge ratio varies over time in accordance with the information flow, applying the full parameterization from Eq. (10) through (13). The optimal hedge ratio in the CC-GARCH framework reduces to $\overline{\rho}\sqrt{h_{s,t} / h_{f,t}}$ by restricting the coefficients ϕ_1 and ϕ_2 to zero in Eq. (12), under the assumption that the correlation coefficient of the error terms remains constant over time. The constant OLS hedge ratio is obtained as $\overline{\rho}\sqrt{\omega_s / \omega_f}$ in this framework by restricting the variance-covariance coefficients α_s, β_s, α_f, β_f, ϕ_1 and ϕ_2, as well as the error-correction coefficients λ_s and λ_f in Eq. (6) and (7) to zero.

The bivariate GARCH models are estimated using futures returns in combination with spot gold returns. The three most traded spot gold products are considered, i.e. 99.95% and 99.99% purities as well as *Au 100g*. Estimation is done using the maximum likelihood technique outlined in Berndt et al. (1974), where the standard errors are corrected for heteroskedasticity and autocorrelation in the residuals (10 lags) according to White (1980) and Newey and West (1987).

4 RESULTS

In order to get an understanding of the Chinese gold market, this chapter first gives summary statistics of trading activity, showing an interesting pattern of contract switching in the futures market. This pattern is utilized to derive time series of gold futures returns, which along with gold spot returns are needed for the evaluation of hedging strategies. The presentation of summary statistics of the returns is followed by comments on the fit of the estimated models and the hedging strategy evaluation results.

Trading activity

Table 2 presents summary statistics for gold futures trading activity, measured as the daily amount of traded futures contracts (*Volume*), daily RMB trading volume (*RMB*), and the corresponding daily open interest (*OI*) at the SHFE. Daily mean, median, and standard deviation of each measure of trading activity are reported for the entire sample period as well as the two subperiods specified above. These statistics are given for all futures contracts together as well as separately for the contracts expiring in June and December. The last three rows of Table 2 contain tests for equality between Period I and Period II means, medians, and variances respectively. For all contracts traded at the SHFE, the mean (median) trading volume is slightly more than 30,000 (22,000) contracts and the standard deviation in trading volume is just above 23,000 contracts. In a comparison across periods, no significant difference in means and medians is observed at the 5% significance level, but a significant decrease in standard deviation from Period I to Period II is seen (at a very low significance level). The corresponding mean (median) RMB trading volume exceeds six (four) billion, with a standard deviation of roughly five billion, over the whole sample period. The mean (median) open interest for all futures contracts is just below 50,000 (45,000), and the corresponding standard deviation in open interest is almost equal to 19,000 contracts. According to the test statistics in Table 2, a significant increase in mean, median, and standard deviation of open interest from Period I to Period II is recorded.

Futures trading activity at the SHFE is clearly concentrated to the two contracts maturing in June and December. From the summary statistics in Table 2, it is observed that from the total average trading volume (open interest) figures, the June contracts account for almost 64% (58%) and the December contracts account for 35% (40%). The total futures market daily RMB trading volume is on average accounted for by the June contracts to 65% and by the December contracts to 33%. Evidently, trading activity in these two contracts totally dominate the SHFE, leaving the contracts maturing in other months with on average only a few percent of the daily trading activity. This feature of the trading activity at the SHFE is further emphasized in Figure 1, where the fraction of daily trading volume for the June and December contracts is illustrated for the entire sample period. In January 2008, when the SHFE initiated gold futures trading, futures trading activity is almost totally concentrated to the June contract. Moreover, as the June 2008 maturity date is approaching, futures trading activity is gradually phased over to the contract maturing in

December 2008. From mid-April, 2008, until mid-October, 2008, the December contract is the most actively traded contract. Figure 1 shows a distinct pattern where one of the June and December contracts dominates futures trading activity for a six-month period, and is then replaced by the other one as the most popular contract for the adjacent six months.

For comparison, Table 3 displays summary statistics for gold spot and SDC trading activity at the SGE for the full sample as well as for the two subperiods. Trading activity is measured as the daily number of kilograms gold traded (*Volume*) and the corresponding RMB value of trading volume (*RMB*) for each of the spot contracts with 99.95% purity, 99.99% purity, and the small-size *Au 100g* contract. For the *SDC* (*T+D*) contract, statistics on daily open interest are reported as well. Considering the entire sample period, it is seen that among the three regular spot contracts, the most actively traded ones are those with purities 99.95% and 99.99%, whereas the small-size contract attracts relatively little trading activity.[8] However, the contract that allows for deferred spot transactions is clearly more popular than the genuine spot contracts. The average daily SDC trading volume of roughly 13,000 kilograms (RMB 2.7 billion) is more than twice the corresponding average trading volume for all spot contracts, which together amounts to roughly 5,000 kilograms (RMB 1.1 billion). Both the spot contracts and the deferred contracts are significantly more actively traded during Period II than during Period I. The most popular spot contract, with purity 99.95%, experiences a significantly increased mean trading volume from 2,345 kilograms (RMB 557 million) in Period I to 3,345 kilograms (RMB 745 million) in Period

[8] We do not report summary statistics for the *Au 50g* contract, which is half the size of, but otherwise similar to the *Au 100g* contract, since it is very infrequently traded.

II at a very low significance level. Likewise, SDC trading volume is significantly larger during Period II than during Period I at the 5% significance level.

Although the contracts are not entirely identical, a gold futures contract and an SDC both offer long and short positions, and can thus be combined with a prevailing gold spot position for hedging purposes. Comparing the summary statistics across Table 2 and Table 3 for the entire sample period, it is noted that the average total futures trading volume of 30,430 kilograms (RMB 6.39 billion) is considerably larger than the corresponding average SDC trading volume which equals 13,009 kilograms (RMB 2.74 billion).[9] Hence, on average, the futures market on the SHFE exhibits a more than twice as large daily trading activity as the SDC market on the SGE. However, SDC daily open interest is on average approximately 50% larger than the corresponding open interest for all futures contracts.[10]

Evidently, both the SHFE and the SGE exhibit a substantial gold trading activity. Figure 2 illustrates the total daily gold trading volume (in kilograms) on the SHFE and the SGE for our entire sample period, separated into spot, SDC, and futures trading. On the whole, futures trading dominates SDC trading, which in turn dominates regular spot trading. The average daily fraction of futures trading volume to total trading volume is 59%, whereas each corresponding fraction of spot and SDC trading volume is 12% and 29% respectively.

[9] A simple *t*-test of each null hypothesis of no difference between futures and SDC trading volume, expressed in kilograms and RMB, is performed. According to the test results (not reported), each null hypothesis can be rejected at a very low significance level.

[10] A simple *t*-test of the null hypothesis of no difference between futures and SDC open interest is performed. According to the test results (not reported), the null hypothesis can be rejected at a very low significance level.

Contract switching and returns

The hedging performance analysis in this article focuses on daily gold spot and futures returns. Based on the futures market trading activity analysis above, in accordance with Figure 1, we only use the contracts with maturity in June and December to calculate futures returns. To ensure that the most actively traded contract is used at all times when calculating futures return series, the systematic pattern in Figure 1 is used to determine when the futures position is "rolled over" from one of the contracts into the other. Consequently, we calculate the first futures return in our sample as the difference between the natural logarithm of the closing futures settlement price on January 10, 2008, and the corresponding closing futures settlement price on January 9, 2008, using the contract maturing in June, 2008. The June 2008 contract is kept until April 24, 2008. On this day, the December 2008 contract reaches a higher trading volume than the June 2008 contract. Thus, the closing futures settlement prices from the December contract are used to calculate the futures returns on April 25, 2008, and onwards. Similarly, the futures return series is "rolled over" on October 28, 2008, April 15, 2009, and October 12, 2009.

Summary statistics for gold futures returns, spot returns, and basis changes are presented in Table 4. Spot returns and basis changes are calculated for each of the spot contracts with purity 99.95% and 99.99%, as well as for the small-size *Au 100g* contract. Together with sample mean, median, and standard deviation, skewness and kurtosis measures for each variable are reported. As above, statistics are given for Period I, Period II, and the entire sample period. In addition, we present results from a test of each hypothesis of equal variable mean, median, and standard deviation respectively across Period I and II. Enclosed are also results from a unit root test for stationarity of each variable. An augmented Dickey-Fuller test (see Fuller, 1996) is used to test each individual null hypothesis that the time series has a unit root. Using the *p*-values from MacKinnon (1996), it is possible to reject each null hypothesis of a unit root at any reasonable significance level. Hence, all variables are considered stationary over the entire sample period.

Gold futures returns and spot returns show very similar characteristics over the entire sample period. Basis changes, which can be interpreted as naïve hedge returns, are considerably less volatile than both futures and spot returns. For example, considering the spot contract with purity 99.95%, spot (futures) return standard deviation equals 0.0156 (0.0157), whereas the standard deviation for the corresponding basis changes is 0.0066. Thus, using the *HP* measure of hedging performance in Eq. (4), it can be concluded that a simple naïve hedging strategy would reduce the spot return variance by as much as 82.33% over the entire sample period.

From a comparison of returns' characteristics across periods, it is noted that Period I standard deviations for returns and basis changes are significantly larger than the corresponding standard deviations during Period II. According to each Levene test, the null hypothesis of a constant variance across the two periods can be rejected for each variable in Table 4, at a very low significance level. Evidently, gold spot and futures returns are significantly more volatile during 2008 than more recently, which is consistent with the increased uncertainty due to the concurrent 2008 financial crisis. We illustrate the development of gold spot and futures prices, and the corresponding returns, over our entire sample period in Figure 3 and Figure 4 respectively. Clearly, gold prices are declining throughout most part of Period I (2008) and exhibit a large variation in particular during the second part of the period. During Period II (2009 and onwards), gold prices experience an incline with considerably less variability than during Period I.

Table 5 shows summary correlation statistics for the futures returns, spot returns, and basis changes. Neither futures nor spot returns show evidence of serial correlation, whereas the corresponding squared return series undoubtedly exhibit significant serial correlation. In addition, both raw and squared futures returns and spot returns are highly contemporaneously cross-correlated. The general features of the data suggest that a bivariate GARCH model is an appropriate modeling framework for the futures and spot returns. Next, we turn to estimation of such models.

Hedging strategy estimation results

Table 6 contains the estimation results from the bivariate GARCH models, with Panel A holding results for the 99.95% purity gold spot; Panel B the 99.99% purity equivalent; and Panel C the *Au 100g*. From the results, we note that the regression model (labeled OLS in Table 6) is not sufficient to capture the joint dynamics of gold spot and futures returns, as the squared residual series contain significant autocorrelation. On the other hand, the two more complicated models, the CC-GARCH and DCC-GARCH, appear well suited for their purpose. The Ljung-Box statistics reported in Table 6 (Q_s and Q_f for spot and futures residuals respectively) indicate no remaining autocorrelation in either raw or squared residuals in either of the models. In addition, each of the GARCH models outperforms the simple regression model in terms of a significantly higher log likelihood value. However, using the DCC rather than the CC specification does not improve the fit of the data.

In the mean equations, the only coefficient that is significantly different from zero is λ_f, which represents the error-correction in the futures mean equation, i.e. the sensitivity of futures returns to the lagged futures basis level. The negative sign of the coefficient implies that, if previous day's basis is large and positive (negative), today's futures price is adjusted downward (upward) to keep futures and spot price in line according to their long run relationship, which reduces (enhances) today's futures return. Note that the corresponding coefficient in the spot mean equations (λ_s) is not significantly different from zero. Hence, only the gold futures price seems to react to lagged deviations from the long run relationship between spot and futures prices. The variance equations of the GARCH models show evidence of high persistence in variance in response to shocks, which is common in studies of financial time series. Note that estimated coefficients in the CC-GARCH and the DCC-GARCH models are very similar; α_s and α_f are close to 0.10, and β_s and β_f are just below 0.90.

At the bottom of each panel in Table 6, the average hedge ratio obtained from estimating each model is presented. Thus, the constant hedge ratio from the regression model for the 99.95% spot gold (Panel A) is estimated to 0.9078, which is below the average hedge ratios from the more complicated models; 0.9441 for the CC-GARCH model and 0.9580 for the CC-GARCH model respectively. Thus, in terms of futures hedging, the more complicated models produce an average estimated hedge ratio closer to one, i.e. to the naïve hedge ratio, than the regression model.

The results across the three spot gold products considered are very similar. This confirms the notion that the three different spot return series show almost identical dynamics. Notably, for each of the three models, the average estimated hedge ratio for the 99.95% spot contract is higher than the corresponding average estimated hedge ratio for the 99.99% spot contract, which in turn is higher than the average estimated hedge ratio for the *AU 100g* contract. For example, the constant OLS hedge ratio between gold futures and each of the spot contracts with 99.95% purity, 99.99% purity, and the *Au 100g* contract respectively, equals 0.9078, 0.8958, and 0.8458. Albeit small, the differences in hedge ratios are consistent with the idea that using gold futures as a hedge together with the different spot contracts is associated with different basis risk. At futures expiration, it is possible to deliver any of the three spot contracts. But the spot contract with 99.95% purity is the cheapest to deliver, and thus constitutes the main underlying security for the gold futures contract.

Hedging performance evaluation

We begin the evaluation of the futures hedging performance with an in-sample analysis for each of the spot gold qualities. Table 7 presents the results for the full sample as well as the two subperiods. As above, the panels A to C distinguish the results for the three different spot gold products. The estimated hedge ratios from the models presented in Table 6 are used to calculate hedging errors. For each period, the mean and standard deviation of the hedging errors, as well as the hedging performance measures *HP* and *EU* are presented for the four different hedge models; naïve, regression, constant correlation (CC) GARCH, and dynamic conditional correlation (DCC) GARCH hedge.

Several interesting results emerge from Table 7. Over the entire sample period, hedging with gold futures can achieve a variance reduction, as measured with the *HP* value, in each spot position of approximately 80%. Interestingly, the variance reduction ability of the futures contract is similar across all three spot contracts, irrespective of which model is used to estimate the hedge ratio. Thus, in terms of variance reduction, it seems not to pay off to estimate the hedge ratio with a more complicated model than the simple naïve hedging strategy. A clear difference in in-sample hedging performance between Period I and Period II is observed. For each spot contract and estimated model, the variance reduction is in general less than 80% during the more volatile Period I, while roughly 90% during the calmer Period II. If we use the utility based hedging performance measure *EU*, taking both mean and variance of the hedged portfolio returns into account, we note that the most complicated model (DCC-GARCH) outperforms the alternative models for each gold spot contract during the entire sample period and Period I. For Period II, the results are mixed, with the regression hedge performing slightly better for the 99.95% and 99.99% purities, and the CC-GARCH hedge resulting in the relatively highest utility level for the *Au 100g* spot contract. However, the differences in utility levels across models are small, and might be negligible.

Table 8 presents out-of-sample hedging strategy evaluation results (with panels A to C representing different spot gold products as above). Unlike the in-sample hedging performance analysis, the out-of-sample exercise is based on a daily updated sequence of estimated hedge ratios. Thus, for each day, the futures hedging scheme is kept conditional upon the current set of information. The *HP* hedging evaluation metric shows that for each spot contract, and each period, the regression hedging strategy is consistently superior to the alternative models. A similar result holds for the *EU* performance measure, except for the spot contract with 99.99% purity, during Period I, when the DCC-GARCH model slightly outperforms the regression hedge.

The out-of-sample results displayed in Table 8 are very similar to the corresponding in-sample results in Table 7. Accordingly, gold futures are more efficient hedge instruments during Period II than during Period I. The regression hedge achieves a variance reduction of 76-77% during Period I and roughly 88-90% during Period II. In addition, the more complex GARCH models, which allow time-varying return variances and correlations, in general underperform the simpler regression hedge models; although the former fit the gold spot and futures return data better.

As an illustration, the naïve hedging errors for the gold spot contract with 99.95% purity are displayed in Figure 5. Clearly, the hedging errors exhibit a considerably lower variability over time than the spot returns displayed in Table 4, demonstrating the excellent variance-reducing qualities of the gold futures contract. Moreover, Figure 5 also confirms the result that the hedging errors are larger, and more variable, during Period I than Period II. Apparently, the relatively worse hedging performance during Period I emanates from the second half of the period; towards the end of 2008. This period of higher variability in gold prices, and worse gold futures hedging performance, coincides with the escalation of the global financial crisis. Thus, it is reasonable to conclude that the financial turmoil during 2008 is the main explanation for the relatively poor performance of the gold futures hedge. It seems that the newly introduced gold futures are adequate hedging vehicles, and do not suffer from any start-up difficulties. This notion is further confirmed by examining the results, presented in Table 9, of an out-of-sample hedging performance analysis of the 99.95% gold spot contracts, breaking up Period I into Period IA, between June 2, 2008, and September 12, 2008, and Period IB, between September 16, 2008, and December 31, 2008. Indeed, the hedging performance measure *HP* barely reaches 70% during Period IB (the crisis period), while it is almost as large as 90% for Period IA.

5 CONCLUDING REMARKS

Gold is universally recognized as both a commodity and a financial asset. China is the world's largest gold producing country and is second only to India in terms of consuming gold. Recently, several important steps towards making China an important center for trading gold as a financial asset have been taken. In 2002, the Shanghai Gold Exchange (SGE) was founded, and has since then grown to be the largest spot gold exchange in the world. In addition, the Shanghai Futures Exchange (SHFE) introduced gold futures trading in 2008. During its very short-lived history, the SHFE gold futures have gained a dominant share among the Chinese gold products, and is currently one of the most actively traded gold futures in the world. This paper analyzes optimal gold futures hedging strategies and evaluates the effectiveness of the hedging strategies in the first two years of Chinese gold futures trading. The purpose is to investigate whether the Chinese gold futures market is a satisfactory avenue for gold investors, refiners, producers and other gold-related companies to hedge their risk exposures.

This paper contributes to previous research in several ways. Firstly, this paper is the first to study the Chinese gold futures market in general, and the gold futures contracts' hedging effectiveness in particular, since the introduction of gold futures trading at the SHFE. Secondly, this paper contributes to the gold futures hedging literature by extending the analysis of Baillie and Myers (1991), which until now is the only existing gold futures hedging paper, by considering several alternative hedging strategies reflecting the latest futures hedging research, using a more comprehensive data set covering all traded gold futures contracts over a two-year period (rather than two selected contracts), and performing a more elaborate hedging performance evaluation across different contracts and over time. Thirdly, this paper's sample period includes the global financial crisis in 2008 that led to high volatility in all asset classes, including gold. This enables an analysis of how the crisis affected gold futures and hedging performance.

This study's results demonstrate that the SHFE gold futures are well-suited for hedging the SGE spot gold products, able to reduce the daily variance of a hedged gold spot position by almost 80% on average in its first year of existence (2008) and by almost 90% in the second year (2009). The relatively worse hedging performance during 2008 is likely to be due to the financial turmoil. Indeed, hedging performance is satisfactory for the first half of 2008, while clearly worse during the second half of 2008, when the global financial crisis escalated. Consequently, the new Chinese gold futures proves to be an attractive and well-needed hedging vehicle for domestic Chinese gold producers and consumers immediately following the introduction.

The results also show that the returns series of both spot and futures products on the Chinese gold market are well-represented by bivariate GARCH models (with constant or dynamic correlations). However, accounting for such effects in the design of hedging strategies does not give any edge relative to the considerably simpler regression-based hedge. All these results are consistent across different spot gold products and hold both in- and out-of-sample.

The results of this study have implications for researchers in finance, exchange officials and regulators, and practitioners with interests in gold futures markets in general, and in the Chinese markets in particular. The main result of the paper is of course that the SHFE gold futures prove to be excellent hedging tools for the gold spot contracts at the SGE. Thus, companies that are involved in refining or producing gold, or e.g. manufacturing jewelry out of gold, would be able to reduce a substantial part of their gold price risk by engaging in gold futures hedging. Likewise, this result holds for individual as well as institutional investors in the gold market.

Officials at the SHFE can be delighted with the result discovered in this paper that the gold futures indeed are satisfactory hedging instruments already in their youth, with a sizable trading activity immediately following the introduction of gold futures at the SHFE. Though, regulators at the SHFE might want to consider an altered futures contract maturity structure, with fewer maturities available, to match the current trading demand, which is more or less concentrated to the June and December contracts, whereas the other ten contract months available on an annual basis record very little trading activity. Finally, the hedging performance analysis indicates that simplicity indeed is a winning strategy when composing the optimal hedge portfolios with gold futures. A simple regression hedge, or even a naïve one-to-one hedge, is almost consistently better than a more complicated GARCH hedge, both in terms of reducing the gold spot variance and within a mean-variance utility framework. Hence, as a suggestion for future research within the commodity futures area, perhaps it would be wise to try to optimize the hedging portfolio with respect to market specific characteristics, as e.g. liquidity, rather than aiming for a more complicated statistical model.

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Table 1: Contract specifications for the SHFE gold futures

Underlying product	Gold
Trading unit	1 kilogram/lot
Quotation Unit	Yuan (RMB)/gram
Contract months	January to December
Minimum tick size	0.01 Yuan/gram
Daily price limit	Within range of 5% above or below the settlement price of the previous trading day
Trading hours	9:00 to 10:15, 10:30 to 11:30, 13:30 to 14:10 , 14:20 to 15:00
Final trading day	The 15th day of the spot month (postponed if legal holidays)
Delivery Duration	16th to 20th day of the spot month (postponed if legal holidays)
Deliverable Grades	Domestic Product: Gold with fineness not less than 99.95% Overseas Product: Gold that is regarded by LBMA as good delivery
Delivery Sites	Designated Warehouses by the Exchange
Delivery Method	Physical Delivery
Transaction Fee	Equal or below 0.02% of transaction value (risk reserve included) 30 Yuan/lot
Minimum Transaction Margin	7% of contract value
Symbol	Au

Source: Shanghai Futures Exchange as of March 12, 2010.

Table 2: Summary statistics for gold futures trading activity

		All contracts			*June*			*December*		
	Statistics	*Volume*	*RMB*	*OI*	*Volume*	*RMB*	*OI*	*Volume*	*RMB*	*OI*
All	*Mean*	30,430	6.39e+9	49,081	19,392	4.19e+9	28,153	10,652	2.12e+9	19,350
	Fraction	1.0000	1.0000	1.0000	0.6373	0.6559	0.5736	0.3501	0.3315	0.3943
	Median	22,448	4.56e+9	43,628	13,612	2.87e+9	26,624	4,394	9.19e+8	15,174
	Standard deviation	23,181	5.03e+9	18,618	23,399	5.33e+9	28,480	15,880	3.10e+9	18,689
Period I	*Mean*	32,286	6.21e+9	41,641	19,347	3.77e+9	21,021	12,327	2.32e+9	18,042
	Fraction	1.0000	1.0000	1.0000	0.5992	0.6065	0.5048	0.3818	0.3736	0.4333
	Median	22,442	4.47e+9	40,484	6,878	1.26e+9	15,592	8,994	1.74e+9	22,952
	Standard deviation	26,781	4.98e+9	11,773	24,076	4.74e+9	21,296	18,968	3.49e+9	13,610
Period II	*Mean*	28,797	6.55e+9	55,625	19,431	4.57e+9	34,426	9,179	1.94e+9	20,502
	Fraction	1.0000	1.0000	1.0000	0.6749	0.6972	0.6189	0.3187	0.2964	0.3686
	Median	22,455	4.67e+9	46,417	15,193	3.26e+9	34,082	2,658	5.64e+8	9,837
	Standard deviation	19,378	5.08e+9	20,193	22,832	5.78e+9	32,312	12,404	2.70e+9	22,180
Test for difference	*F-test, p-value*	0.0883	0.4508	0.0000	0.9676	0.0902	0.0000	0.0246	0.1645	0.1363
	KW-test, p-value	0.7576	0.2660	0.0000	0.2129	0.0515	0.0000	0.0059	0.0211	0.6724
	L-test, p-value	0.0005	0.7339	0.0000	0.0345	0.2347	0.0000	0.0621	0.5460	0.0000

Table 2 contains summary statistics for gold futures number of traded contracts (*Volume*), RMB trading volume (*RMB*), and open interest (*OI*). Period I is between January 9, 2008, and December 31, 2008 and Period II is between January 1, 2009, and February 12, 2010. The last three rows contain *p*-values from an *F*-test for equality between period means, a Kruskal-Wallis (*KW*) one-way ANOVA by ranks test for equality between period medians, and a Levene (*L*) test for equality between period variances.

Table 3: Summary statistics for gold spot and SDC trading activity

		Quality 99.95%		*Quality* 99.99%		*AU* 100 *g*		*SDC* (*T* + *D*)		
	Statistics	*Volume*	*RMB*	*Volume*	*RMB*	*Volume*	*RMB*	*Volume*	*RMB*	*OI*
All	*Mean*	2,877	6.57e+8	2,176	4.27e+8	68	1.43e+7	13,009	2.74e+9	77,003
	Median	2,800	6.10e+8	1,762	3.64e+8	58	1.20e+7	11,886	2.41e+9	74,438
	Standard deviation	1,517	2.85e+8	1,407	2.47e+8	45	9.43e+6	6,952	1.65e+9	18,752
Period I	*Mean*	2,345	5.57e+8	2,008	3.93e+8	70	1.39e+7	12,246	2.39e+9	62,870
	Median	2,278	4.92e+8	1,831	3.64e+8	58	1.17e+7	11,748	2.23e+9	60,952
	Standard deviation	1,655	2.70e+8	933	1.72e+8	50	2.02e+6	6,056	1.21e+9	10,373
Period II	*Mean*	3,345	7.45e+8	2,324	4.58e+8	66	1.46e+7	13,681	3.05e+9	89,434
	Median	3,266	6.93e+8	1,736	3.61e+8	57	1.24e+7	11,952	2.56e+9	87,226
	Standard deviation	1,207	2.69e+8	1,708	2.95e+8	40	8.98e+6	7,601	1.91e+9	15,363
Test for difference	*F-test, p-value*	0.0000	0.0000	0.0109	0.0031	0.2725	0.3604	0.0193	0.0000	0.0000
	KW-test, p-value	0.0000	0.0000	0.5810	0.1429	0.9586	0.0608	0.0828	0.0002	0.0000
	L-test, p-value	0.0029	0.1373	0.0001	0.0000	0.0048	0.3664	0.0478	0.0000	0.0000

Table 3 contains summary statistics for gold spot and SDC number of traded contracts (*Volume*), RMB trading volume (*RMB*), and open interest (*OI*). Period I is between January 9, 2008, and December 31, 2008 (241 days) and Period II is between January 1, 2009, and February 12, 2010 (274 days). The last three rows contain p-values from an F-test for equality between period means, a Kruskal-Wallis (*KW*) one-way ANOVA by ranks test for equality between period medians, and a Levene (*L*) test for equality between period variances.

Table 4: Summary statistics for gold futures returns, spot returns and basis changes

			Quality 99.95%		*Quality* 99.99%		*AU* 100 *g*	
	Statistics	*Futures*	*Spot*	*Basis*	*Spot*	*Basis*	*Spot*	*Basis*
All	*Mean*	1.38e-4	2.74e-4	-1.36e-4	2.68e-4	-1.31e-4	2.84e-4	-1.46e-4
	Median	8.27e-4	1.03e-3	-6.66e-5	9.92e-4	-7.06e-6	1.12e-3	-8.85e-5
	Standard deviation	0.0157	0.0156	0.0066	0.0154	0.0065	0.0146	0.0066
	Skewness	-0.2888	0.0077	0.5160	0.0223	0.6235	0.0104	0.3364
	Kurtosis	5.1435	6.7938	18.832	7.1331	20.260	6.9827	16.124
	Unit root test, p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Period I	*Mean*	-6.92e-4	-3.77e-4	-3.15e-4	-3.80e-4	-3.13e-4	-3.50e-4	-3.42e-4
	Median	4.99e-4	2.92e-4	-2.15e-4	1.58e-4	3.66e-5	1.09e-3	-2.89e-4
	Standard deviation	0.0184	0.0184	0.0084	0.0182	0.0085	0.0171	0.0084
	Skewness	-0.4448	0.0317	0.5180	0.0623	0.6199	0.0490	0.4712
	Kurtosis	4.0922	6.2106	14.423	6.4585	14.598	6.3343	12.465
Period II	*Mean*	8.65e-4	8.45e-4	2.04e-5	8.36e-4	2.91e-5	8.39e-4	2.61e-5
	Median	1.28e-3	1.62e-3	2.13e-5	1.13e-3	-1.17e-5	1.35e-3	-4.61e-5
	Standard deviation	0.0128	0.0127	0.0043	0.0124	0.0040	0.0119	0.0043
	Skewness	0.3300	0.0908	0.3401	0.0681	0.2190	0.0567	-0.5023
	Kurtosis	6.0441	5.2855	6.3573	5.4171	3.9593	5.8217	4.4543
Test	*F-test, p-value*	0.2613	0.3761	0.5634	0.3718	0.5520	0.3571	0.5251
	KW-test, p-value	0.5633	0.5609	0.7856	0.5730	0.8257	0.6745	0.4352
	L-test, p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 4 contains summary statistics for gold futures returns $\ln(F_t / F_{t-1})$, gold spot returns $\ln(S_t / S_{t-1})$, and basis changes $\ln(F_t / S_t) - \ln(F_{t-1} / S_{t-1})$. Period I is between January 9, 2008, and December 31, 2008 (241 days) and Period II is between January 1, 2009, and February 12, 2010 (274 days). The augmented Dickey-Fuller test (Fuller, 1996) is used to test the null hypothesis that each time series has a unit root. For each series, a MacKinnon (1996) one-sided *p*-value under each null hypothesis is reported. The last three rows contain *p*-values from an ANOVA *F*-test for equality between period means, a Kruskal-Wallis (*KW*) one-way ANOVA by ranks test for equality between period medians, and a Levene (*L*) test for equality between period variances.

Table 5: Correlation statistics for gold futures returns, spot returns and basis changes

		Quality 99.95%		*Quality* 99.99%		*AU* 100 *g*	
Statistics	*Futures*	*Spot*	*Basis*	*Spot*	*Basis*	*Spot*	*Basis*
Raw variable correlations							
Rho (*lag* = 1)	0.065	-0.035	-0.353	-0.032	-0.360	-0.008	-0.269
Rho (*lag* = 2)	0.012	0.071	0.016	0.077	0.010	0.053	-0.019
Ljung-Box Q(10)	6.842	11.22	80.47	12.53	81.85	9.196	52.71
p-value of Ljung-Box	0.740	0.341	0.000	0.251	0.000	0.514	0.000
Squared variable correlations							
Rho (*lag* = 1)	0.099	0.108	0.451	0.104	0.475	0.091	0.413
Rho (*lag* = 2)	-0.014	0.048	0.147	0.053	0.148	0.057	0.143
Ljung-Box Q(10)	82.70	45.13	137.8	46.97	149.0	44.45	132.6
p-value of Ljung-Box	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 5 contains correlation statistics for gold futures returns $\ln(F_t / F_{t-1})$, gold spot returns $\ln(S_t / S_{t-1})$, and basis changes $\ln(F_t / S_t) - \ln(F_{t-1} / S_{t-1})$.

Table 6: Estimates of bivariate models for gold spot returns and futures returns

Panel A: Results using 99.95% spot gold

		OLS		*CC-GARCH*		*DCC-GARCH*	
	Coefficient	*Estimate*	*p-value*	*Estimate*	*p-value*	*Estimate*	*p-value*
Mean	μ_s	2.64e-4	0.6933	5.69e-4	0.3263	7.35e-4	0.2164
	μ_f	1.24e-4	0.8591	7.13e-4	0.2262	7.47e-4	0.2147
	λ_s			9.08e-3	0.8115	-0.0257	0.4845
	λ_f			-0.1289	0.0021	-0.1769	0.0000
Variance	ω_s	2.42e-4	0.0000	3.16e-6	0.0673	3.72e-6	0.0039
	ω_f	2.45e-4	0.0000	3.25e-6	0.0124	7.19e-6	0.0003
	α_s			0.0964	0.0000	0.1223	0.0000
	α_f			0.1048	0.0000	0.1043	0.0000
	β_s			0.8986	0.0000	0.8611	0.0000
	β_f			0.8903	0.0000	0.8664	0.0000
Correlation	ρ	0.9120	0.0000	0.9391	0.0000		
	ϕ_1					0.0407	0.0027
	ϕ_2					0.9564	0.0000
Residuals (*Raw*)	Q_s	10.714	0.3803	6.3223	0.7875	6.0129	0.8142
	Q_f	6.3786	0.7825	4.4303	0.9259	4.6887	0.9110
Residuals (*Squared*)	Q_s	45.310	0.0000	7.9370	0.6350	8.3979	0.5900
	Q_f	82.052	0.0000	10.001	0.4404	10.305	0.4142
Log Likelihood		3,275.3		3,420.5		3,420.8	
Average Hedge Ratio	$\bar{\varphi}$	0.9078		0.9441		0.9580	

Panel B: Results using 99.99% spot gold

		OLS		*CC-GARCH*		*DCC-GARCH*	
	Coefficient	*Estimate*	*p-value*	*Estimate*	*p-value*	*Estimate*	*p-value*
Mean	μ_s	2.68e-4	0.6883	4.03e-4	0.4647	5.73e-4	0.3167
	μ_f	1.38e-4	0.8436	4.28e-4	0.4626	4.73e-4	0.4268
	λ_s			-0.0335	0.3723	-0.0374	0.2991
	λ_f			-0.1760	0.0003	-0.1930	0.0001
Variance	ω_s	2.36e-4	0.0000	3.33e-6	0.0284	4.43e-6	0.0096
	ω_f	2.45e-4	0.0000	4.10e-6	0.0059	5.91e-6	0.0011
	α_s			0.0994	0.0000	0.1022	0.0000
	α_f			0.1092	0.0000	0.0939	0.0000
	β_s			0.8943	0.0000	0.8846	0.0000
	β_f			0.8824	0.0000	0.8800	0.0000
Correlation	ρ	0.9127	0.0000	0.9406	0.0000		
	ϕ_1					0.0398	0.0507
	ϕ_2					0.9549	0.0000
Residuals (*Raw*)	Q_s	12.026	0.2833	7.1439	0.7118	7.0463	0.7211
	Q_f	6.3786	0.7825	4.9401	0.8951	5.2509	0.8738
Residuals (*Squared*)	Q_s	47.285	0.0000	7.7979	0.6486	7.7277	0.6554
	Q_f	82.092	0.0000	10.343	0.4109	10.117	0.4303
Log Likelihood		3,284.5		3,437.5		3,436.3	
Average Hedge Ratio	$\overline{\varphi}$	0.8958		0.9255		0.9338	

Panel C: Results using *Au 100g* spot gold

		OLS		*CC-GARCH*		*DCC-GARCH*	
	Coefficient	*Estimate*	*p-value*	*Estimate*	*p-value*	*Estimate*	*p-value*
Mean	μ_s	2.59e-4	0.6815	3.50e-4	0.4805	4.40e-4	0.3943
	μ_f	1.18e-4	0.8645	2.19e-4	0.7030	1.62e-4	0.7771
	λ_s			2.10e-3	0.9546	-0.0139	0.6529
	λ_f			-0.1395	0.0009	-0.1644	0.0000
Variance	ω_s	2.11e-4	0.0000	2.03e-6	0.0257	3.49e-6	0.0127
	ω_f	2.43e-4	0.0000	2.76e-6	0.0035	5.01e-6	0.0006
	α_s			0.0781	0.0000	0.0963	0.0000
	α_f			0.0868	0.0000	0.0871	0.0000
	β_s			0.9164	0.0000	0.8944	0.0000
	β_f			0.9066	0.0000	0.8931	0.0000
Correlation	ρ	0.9080	0.0000	0.9357	0.0000		
	ϕ_1					0.0700	0.0007
	ϕ_2					0.9204	0.0000
Residuals (*Raw*)	Q_s	8.7721	0.5539	5.9658	0.8181	5.5229	0.8536
	Q_f	6.3786	0.7825	5.2364	0.8748	5.6858	0.8409
Residuals (*Squared*)	Q_s	45.000	0.0000	7.7723	0.6511	8.4666	0.5836
	Q_f	82.033	0.0000	9.4998	0.4854	9.8883	0.4503
Log Likelihood		3,300.5		3,447.4		3,462.2	
Average Hedge Ratio	$\overline{\varphi}$	0.8458		0.8758		0.8870	

Table 7: In-sample hedging performance

	Period I				Period II				Period I and II			
Portfolio	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*
A: Quality 99.95%												
No hedge	-3.77e-4	0.0184	-	-	8.54e-4	0.0127	-	-	2.74e-4	0.0156	-	-
Naive hedge	3.15e-4	0.0084	0.7898	-4.22e-6	-2.04e-5	0.0043	0.8842	-1.04e-4	1.36e-4	0.0066	0.8233	-5.73e-5
Regression hedge	2.51e-4	0.0082	0.8007	-5.16e-5	5.93e-5	0.0042	0.8884	-2.16e-5	1.49e-4	0.0064	0.8319	-3.52e-5
CC GARCH hedge	4.83e-4	0.0085	0.7874	1.57e-4	5.87e-5	0.0043	0.8838	-2.56e-5	2.56e-4	0.0066	0.8209	6.02e-6
DCC GARCH hedge	4.81e-4	0.0084	0.7887	1.60e-4	2.54e-5	0.0043	0.8851	-5.79e-5	2.39e-4	0.0066	0.8222	4.45e-5
B: Quality 99.99%												
No hedge	-3.80e-4	0.0182	-	-	8.36e-4	0.0124	-	-	2.68e-4	0.0154	-	-
Naive hedge	3.13e-4	0.0085	0.7821	-1.31e-5	-2.91e-5	0.0040	0.8970	-9.99e-5	1.31e-4	0.0065	0.8218	-5.91e-5
Regression hedge	2.41e-4	0.0082	0.7954	-6.54e-5	6.10e-5	0.0038	0.9042	-4.80e-6	1.45e-4	0.0063	0.8331	-3.28e-5
CC GARCH hedge	5.00e-4	0.0085	0.7807	1.72e-4	5.89e-5	0.0039	0.9025	-8.17e-6	2.66e-4	0.0065	0.8221	7.67e-5
DCC GARCH hedge	5.05e-4	0.0084	0.7869	1.86e-4	4.93e-5	0.0039	0.9029	-1.75e-5	2.63e-4	0.0064	0.8263	7.82e-5

Table 7 (cont.): In-sample hedging performance

	Period I				Period II				Period I and II			
Portfolio	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*
C: *Au* 100*g*												
No hedge	-3.50e-4	0.0171	-	-	8.39e-4	0.0119	-	-	2.84e-4	0.0146	-	-
Naive hedge	3.42e-4	0.0084	0.7585	2.41e-5	-2.61e-5	0.0043	0.8689	-1.10e-4	1.46e-4	0.0066	0.7981	-4.72e-5
Regression hedge	2.36e-4	0.0078	0.7917	-3.89e-5	1.07e-4	0.0040	0.8859	3.41e-5	1.67e-4	0.0061	0.8256	3.43e-7
CC GARCH hedge	4.59e-4	0.0080	0.7802	1.69e-4	1.16e-4	0.0040	0.8863	4.33e-5	2.76e-4	0.0062	0.8183	1.02e-4
DCC GARCH hedge	5.08e-4	0.0079	0.7867	2.26e-4	1.09e-4	0.0040	0.8878	3.70e-5	2.95e-4	0.0061	0.8229	1.26e-4

Table 7 contains the in-sample hedging performance results for Period I, between January 9, 2008, and December 31, 2008 (241 days), and Period II, between January 1, 2009, and February 12, 2010 (274 days). For each period, the mean and standard deviation of the hedging errors, as well as the hedging performance measures *HP*, which measures the variance reduction achieved by using futures relative the un-hedged variance of gold spot returns (*No hedge*), and *EU*, which measures hedging performance in an expected utility framework, is presented for the four different hedge models; naïve, regression, constant correlation (CC) GARCH, and dynamic conditional correlation (DCC) GARCH. Results are presented for large-size gold spot contracts, with purity of 99.95% and 99.99% respectively, and the small-size *AU* 100*g* contract.

Table 8: Out-of-sample hedging performance

	Period I				Period II				Period I and II			
Portfolio	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*
A: Quality 99.95%												
No hedge	-1.74e-3	0.0204	-	-	8.45e-4	0.0127	-	-	4.91e-4	0.0158	-	-
Naive hedge	7.91e-5	0.0099	0.7654	-3.59e-4	-2.04e-5	0.0043	0.8842	-1.04e-4	1.42e-5	0.0068	0.8157	-1.92e-4
Regression hedge	1.51e-4	0.0097	0.7733	-2.72e-4	6.20e-5	0.0042	0.8879	-1.93e-5	9.30e-5	0.0067	0.8219	-1.06e-4
CC GARCH hedge	-8.75e-5	0.0105	0.7339	-5.84e-4	5.37e-5	0.0044	0.8824	-3.15e-5	4.64e-6	0.0071	0.7968	-2.23e-4
DCC GARCH hedge	2.95e-5	0.0103	0.7433	-4.50e-4	5.45e-5	0.0044	0.8825	-3.06e-5	4.58e-5	0.0070	0.8023	-1.76e-4
B: Quality 99.99%												
No hedge	-1.82e-3	0.0202	-	-	8.36e-4	0.0124	-	-	4.82e-4	0.0155	-	-
Naive hedge	7.05e-5	0.0099	0.7584	-3.74e-4	-2.91e-5	0.0040	0.8970	-9.99e-5	5.53e-6	0.0067	0.8158	-1.94e-4
Regression hedge	1.40e-4	0.0097	0.7689	-2.85e-4	6.09e-5	0.0038	0.9038	-5.23e-6	8.83e-5	0.0065	0.8248	-1.02e-4
CC GARCH hedge	-4.69e-5	0.0105	0.7323	-5.39e-4	3.67e-5	0.0039	0.9013	-3.11e-5	7.66e-6	0.0069	0.8023	-2.07e-4
DCC GARCH hedge	2.15e-4	0.0103	0.7413	-2.60e-4	4.71e-5	0.0039	0.9008	-2.11e-5	1.06e-4	0.0068	0.8074	-1.03e-4

Table 8 (cont.): Out-of-sample hedging performance

	Period I				Period II				Period I and II			
Portfolio	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*
C: *AU* 100*g*												
No hedge	-1.79e-4	0.0190	-	-	8.39e-4	0.0119	-	-	4.85e-4	0.0148	-	-
Naive hedge	7.39e-5	0.0099	0.7274	-3.69e-4	-2.61e-5	0.0043	0.8689	-1.10e-4	8.63e-6	0.0068	0.7880	-1.99e-4
Regression hedge	1.46e-4	0.0093	0.7603	-2.44e-4	1.05e-4	0.0040	0.8851	3.16e-5	1.19e-4	0.0064	0.8137	-6.34e-5
CC GARCH hedge	-1.12e-4	0.0101	0.7194	-5.67e-4	5.10e-5	0.0043	0.8689	-3.31e-5	-5.58e-6	0.0069	0.7833	-2.18e-4
DCC GARCH hedge	-4.77e-5	0.0099	0.7296	-4.87e-4	5.70e-5	0.0042	0.8740	-2.38e-5	2.06e-5	0.0067	0.7914	-1.84e-4

Table 8 contains the out-of-sample hedging performance results for the second half of Period I, between June 2, 2008, and December 31, 2008 (146 days), and Period II, between January 1, 2009, and February 12, 2010 (274 days). For each period, the mean and standard deviation of the hedging errors, as well as the hedging performance measures *HP*, which measures the variance reduction achieved by using futures relative the un-hedged variance of gold spot returns (*No hedge*), and *EU*, which measures hedging performance in an expected utility framework, is presented for the four different hedge models; naïve, regression, constant correlation (CC) GARCH, and dynamic conditional correlation (DCC) GARCH. Results are presented for large-size gold spot contracts, with purity of 99.95% and 99.99% respectively, and the small-size *AU* 100*g* contract.

Table 9: Out-of-sample hedging performance for 99.95% gold spot, during 2008

	Period IA				Period IB			
Portfolio	*Mean*	*St. Dev.*	*HP*	*EU*	*Mean*	*St. Dev.*	*HP*	*EU*
No hedge	-2.06e-3	0.0158	-	-	-1.77e-3	0.0241	-	-
Naive hedge	-5.12e-5	0.0052	0.8901	-1.75e-4	2.13e-4	0.0131	0.7075	-5.54e-4
Regression hedge	-1.41e-4	0.0053	0.8880	-2.66e-4	4.51e-4	0.0128	0.7202	-2.83e-4
CC GARCH hedge	-1.11e-4	0.0054	0.8834	-2.42e-4	-6.32e-5	0.0140	0.6646	-9.43e-4
DCC GARCH hedge	-1.47e-4	0.0054	0.8848	-2.77e-4	2.11e-4	0.0137	0.6778	-6.34e-4

Table 9 contains the out-of-sample hedging performance results for Period IA, between June 2, 2008, and September 12, 2008, (74 days), and Period IB, between September 16, 2008, and December 31, 2008 (72 days). For each period, the mean and standard deviation of the hedging errors, as well as the hedging performance measures *HP*, which measures the variance reduction achieved by using futures relative the un-hedged variance of gold spot returns (*No hedge*), and *EU*, which measures hedging performance in an expected utility framework, is presented for the four different hedge models; naïve, regression, constant correlation (CC) GARCH, and dynamic conditional correlation (DCC) GARCH.

Figure 1: Fraction of daily gold futures contract trading volume

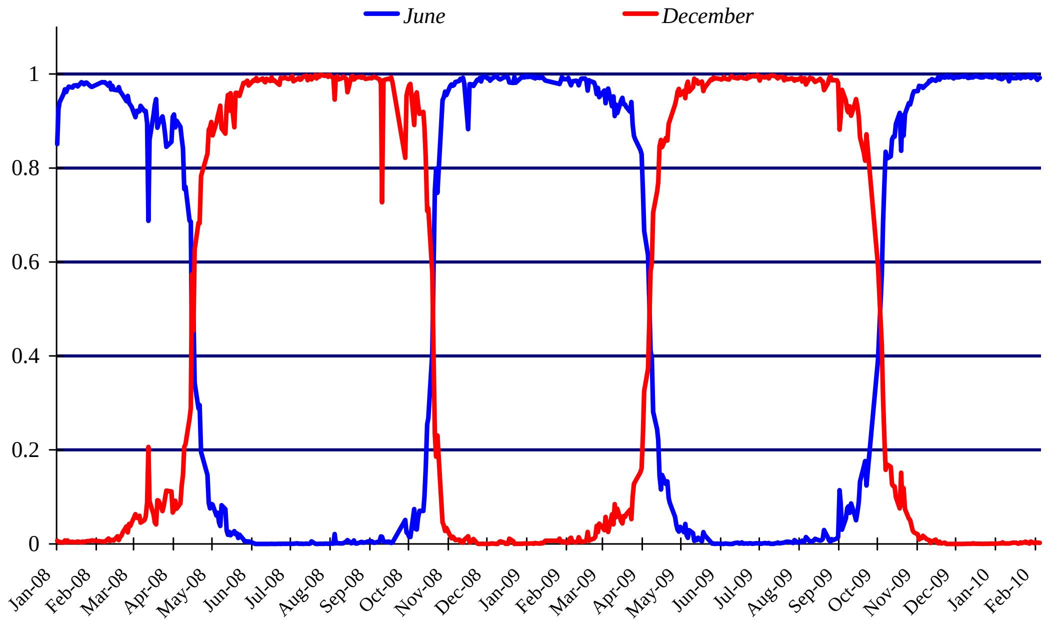

Figure 2: Total gold spot, SDC, and futures trading volume

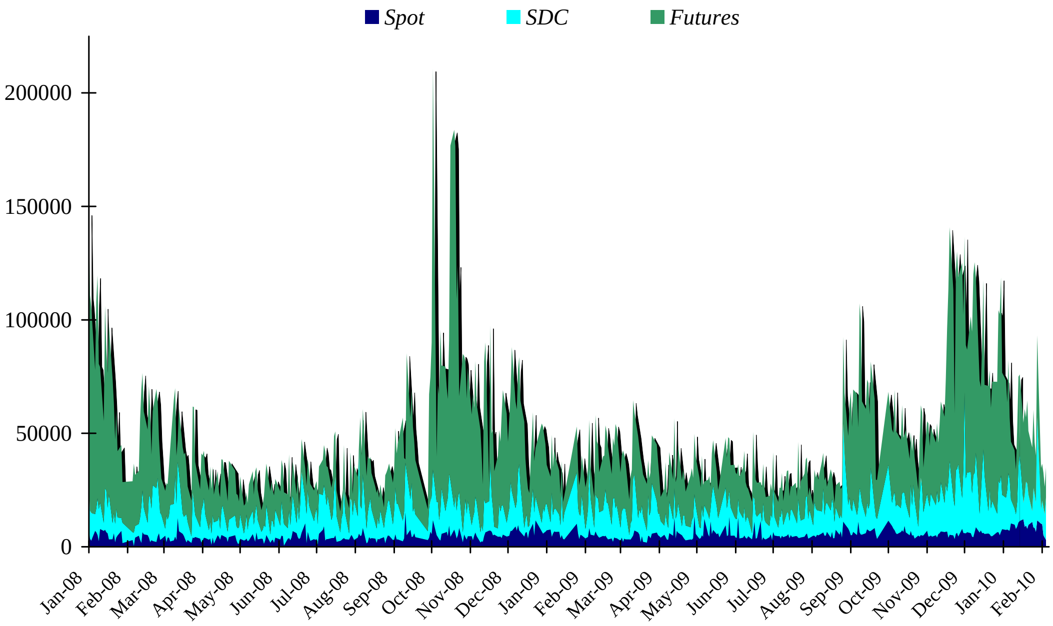

Figure 3: Gold spot and futures prices

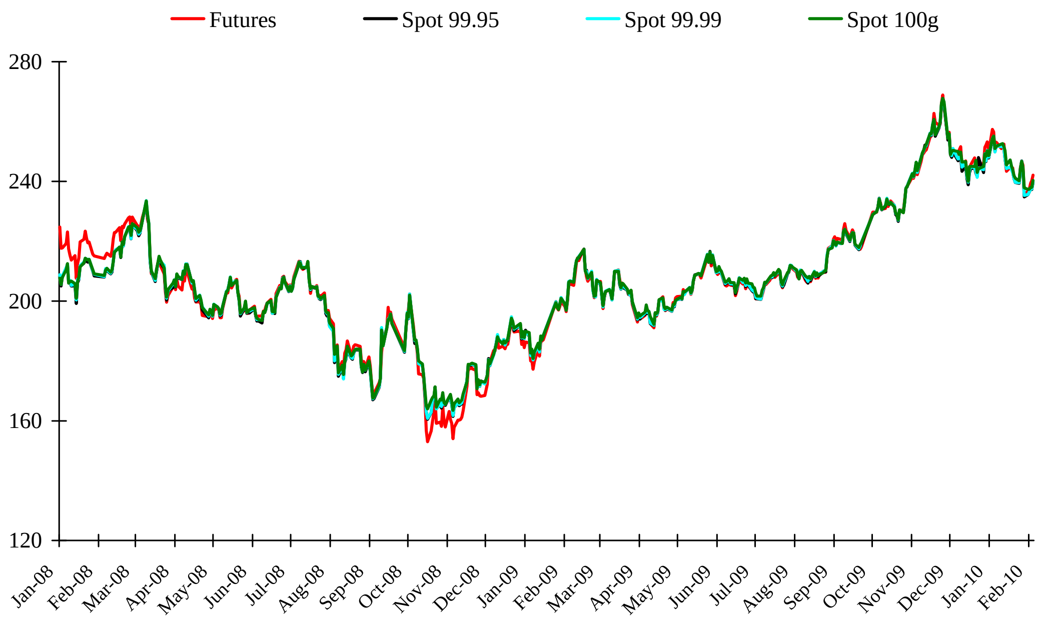

Figure 4: Spot and futures returns

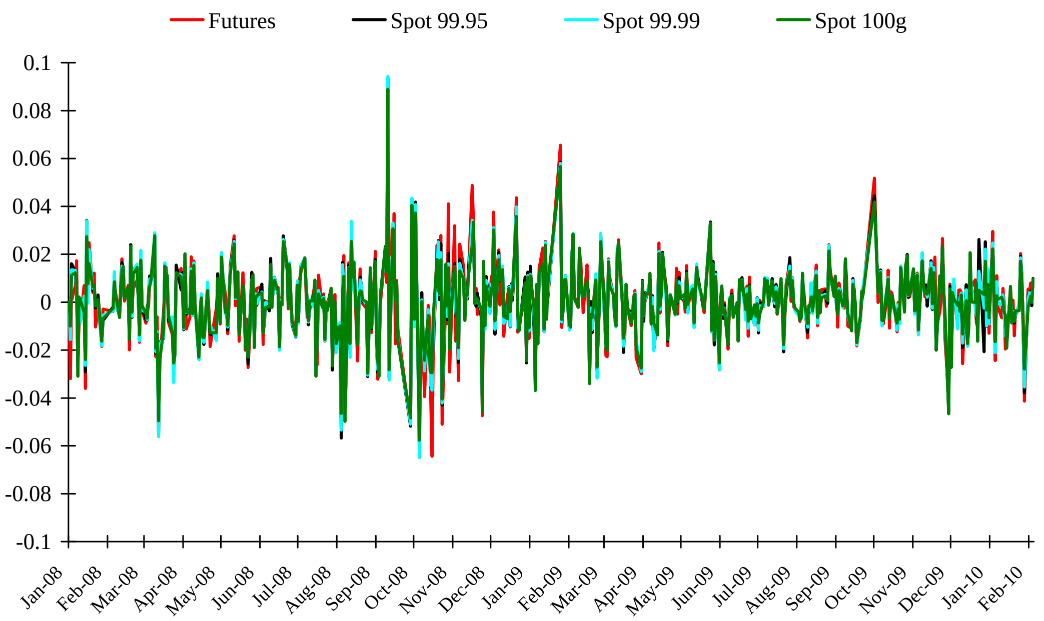

Figure 5: Naive futures hedge errors for the 99.95% gold spot