The implied convenience yields of precious metals: Safe haven versus industrial usage

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JEL classification: G14, G15.

Keywords: Precious metals, convenience yields; cross-market.

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1 Introduction

The flow of investment capital into commodity-related sectors have increased more than tenfold in the last decade. In particular, soaring prices and increasing volatility have elevated precious metals to a stand-alone asset class in the investment community. The increasing importance of precious metals in tactical asset allocation is evidenced by the sharp rise in the number of exchange-traded funds linked to precious metals. According to Solt and Swanson (1981), precious metals are widely regarded as alternative investments to equity and bonds. Jaffe (1989), Lucey et al (2004) and Hillier et al (2006) examine the diversification benefits of precious metals in portfolio allocations. Furthermore, precious metals have all along been regarded as an effective hedge against expected inflationary pressures as well as a safe haven during times of financial turmoil. Baur and Lucey (2010) confirms that this is indeed the case for gold. During September 2008, the Wall St meltdown brought on by the US sub-prime crisis sees the collapse of several financial institutions. In that same month, the NYMEX gold futures market recorded its largest one-day price jump of \$70/oz.

The cost-of-carry argument focuses on storage costs, including interest foregone, warehousing and shrinkage. But many commodities constitute essential inputs that are heavily consumed by relevant industry groups. Whether it is due to supply shocks that affect production level, or a surge in industrial demand, there is a convenience yield cy_{it} associated with maintaining a physical stockpile of commodity i. The notion of convenience yield in commodity markets is akin to liquidity premium in equity markets. The theory of storage predicts low cy_{it} when there is an abundance of the commodity, and high cy_{it} when stockpiles are running low i.e. stock out. These predictions are empirically confirmed by Telser (1958).

We outline the cost-of-carry relation with convenience yield in equation(1). Denote S_{it} and F_{it} as the spot and futures prices of commodity i; r_f and u are the continuously compounded annual risk-free rate and percentage storage cost, both of which are associated with physical ownership. cy_{it} is the benefit of convenience from physically owning the commodity. If $r_f+u =$

cy_{it}, then $F_{it} = S_{it}$. Since the costs and benefit of physical ownership balance out, the market is generally indifferent between owning commodity i directly, or through a futures contract. Similarly, if $r_f + u > (<) cy_{it}$, then $F_{it} > (<) S_{it}$ since the costs (benefit) of physical ownership outweighs the benefit (costs). Since cy_{it} is the only unobservable variable, we can extract a time-series of implied convenience yield from equation(1) using other observable variables.

$$F_{it} = S_{it} e^{(r_f + u - cy_{it})(T-t)}$$

$$cy_{it} = r_f + u - Ln(\frac{S_{it}}{F_{it}})/(T-t) \tag{1}$$

Our motivation is to acquire a better understanding of the nature of cross-market interactions among the convenience yields (cy_{it}) of four precious metals: Gold (Gd), Platinum (Pl), Palladium (Pd) and Silver (Si). We analyze cy_{it}, i ={Gd, Pl, Pd, Si} that is implied from equation(1) using Tokyo Commodity Exchange (TOCOM) futures prices, London Bullion Market Association (LBMA) Gd and Si price fixings and London Platinum Palladium Market (LPPM) for Pl and Pd price fixings. TOCOM is the only exchange that trades futures contracts on all four precious metals. LBMA and LPPM, which are wholesale trading centers, are widely accepted as centralized spot markets for Gd, Si, and for Pl, Pd respectively.

We have three related objectives. First, we analyze the cross-market time-series dynamics among the cy_{it} for {Gd, Pl, Pd, Si}. Second, we test if the more influential cy_{it} of one precious metal also affects the return, volatility and/or volume dynamics of a less influential precious metal. Third and most importantly, we examine if the information content of cy_{it} varies over time depending on the extent of each precious metal's global industrial consumption. For Gd, industrial usage constitutes only 12% of global consumption. In stark contrast, industrial usage constitutes more than 60% of global consumption for silver[1]. Pl and Pd are somewhat caught in between. Both metals are more precious than Si and they feature more prominently in various investment strategies. However, unlike Gd, around 50% of global Pd and Pl output

[1]For example, batteries, electronic circuit boards, brazing and soldering. Source: http://www.silverinstitute.org/silver uses.php

are consumed by the automobile industry[2].

It is reasonable to argue that the perceived convenience yield from physical ownership is heavily influenced by the dominant investor clientele. Given the entrenched perception of Gd as a safe haven, it becomes increasingly convenient for investors to hold gold during times of financial turbulence. In contrast, manufacturing firms find it increasingly beneficial and convenient to stockpile Si, Pl and/or Pd during good economic times to ensure that their own production process is not disrupted by supply shocks to an essential input commodity. Fama and French (1988) examine the time-series of cy_{it} for aluminum, copper, lead, tin, and zinc. They find that, near business cycle peaks, positive demand shocks for these industrial metals reduce inventory levels, thereby generating large cy_{it}.

The preceding argument implies that the nature of any existing cross-market interactions between cy_{it} and the trading dynamics of {Gd, Pl, Pd, Si} will vary over time depending on the state of the global economy. Specifically, we expect the cross-market influence exerted by Gd's cy_{it} to be enhanced (diluted) during (after) a large scale financial crisis, due to its safe haven status. Similarly, we expect the cy_{it} of Si, which has the largest industrial usage, to exert a greater influence on the other precious metal markets during good economic times. If our argument holds, it would be empirically manifested in the cross-market influence of cy_{it} oscillating from Gd on one end to Si on the other end, as the global economy enters and exists the Asian Financial Crisis (AFC), the Dotcom Crisis (DCC) and the Global Financial Crisis (GFC). This constitutes both the main proposition and the title of our paper.

Many existing studies on commodity futures are based on NYMEX and/or LME markets. This is despite the fact that TOCOM is ranked sixth globally in terms of commodity futures trading volume in 2006. It is the largest commodity exchange in Japan, handling 83% of all commodity futures trades. Although LME is the world's largest metal exchange,

[2]This is primarily for making catalyst converters, which control exhaust fumes emissions from passenger vehicle mufflers. It converts up to 90% of harmful gases from auto-exhaust fumes (hydrocarbons, carbon monoxide and nitrogen oxide) into less harmful substances (nitrogen, carbon dioxide and water vapor). Source: http://www.palladiumcoins.com/productionJM.html. Palladium: Metal of the 21st Century.

it specializes in non-ferrous metals[3]. In contrast, TOCOM is renowned for trading precious metal derivatives, including gold, platinum, palladium and silver[4].

Studies on precious metals examine one or more of {Gd, Pl, Pd, Si}. Many earlier studies focus on the cointegrating relation between gold and silver[5]. Ciner (2001) argues that a long-run relationship between gold and silver prices exist since silver is historically being regarded as a substitute for gold as an investment asset. However, the cointegrating relation has weakened over time as Si is increasingly being consumed as an industrial metal. Ciner (2001) confirms that the long-run equilibrium pricing between Gd and Si that is documented in earlier studies does not exist for the sample period 1990 to 1998. Subsequent studies apply more sophisticated analysis to uncover evidence of a more subtle pricing link between Gd and Si. This includes fractional cointegration analysis Liu and Chou (2003) and Escribano and Granger (1998), and time-varying cointegration analysis in Lucey and Tully (2006) and Gerolimetto et al (2006).

The main critique on gold-silver studies stems from the argument that gold is commonly regarded as a storage of value that the central banks in many countries hold as foreign reserves. In stark contrast, the biggest global consumption of silver is driven by various industrial usages[6]. In 2009, industrial applications consume around three times as much silver as investment and jewellery[7]. Our findings confirm that the pricing relationship among precious metals is indeed time-varying. More importantly, we provide a simple economic argument to show that the time-varying nature of the pricing relation between Gd and Si is associated with the state of the global economy i.e. normal versus crisis period. This is due to the contrasting perception of Gd as a safe haven and Si as an industrial metal.

VAR estimation on cy_{it} reveals significant cross-market interactions among the four pre-

[3]For example, copper, aluminum, tin, nickel etc.

[4]In addition to the standard futures, TOCOM also trades options and mini-futures contracts on both gold and platinum.

[5]See Solt and Swanson (1981), Chan and Mountain (1988) and Frank and Stengos (1989).

[6]For example, batteries, electronic circuit boards, brazing and soldering.

[7]Source: http://www.silverinstitute.org/supply demand.php

cious metals. VAR results show that the cy_{it} of GD has the most cross-market influence. The lagged cy_{it} of Si and Pl are also significant in the cy_{it} of other metals. The cy_{it} of Pd is not significant beyond its own lag dynamics. Sub-sample analysis confirms that the pecking-order of influence is time-varying and oscillates between Gd and Si as the estimation window progresses across the three financial crises during our sample period.

We separately include the lagged cy_{it} of Gd, Si and Pl as exogenous variables into three rounds of VAR estimations on returns (r_{it}), volatility (σ_{it}) and trading volume (v_{it}). We confirm that cy_{it} provides incremental information to the various measures of trading activity to varying degrees. The significance of cy_{it} is more evident in the r_{it} and σ_{it} VARs compared to v_{it}. Our moving window estimation reveals similar evidence that the relative significance of cy_{it} shifts between Gd and Si. Specifically, the cy_{it} of Si is highly significant in the r_{it} of all four metals during normal economic conditions. The cy_{it} of Gd affects the short-run dynamics of σ_{it} across all four metals during times of economic crisis. The two findings support our main proposition that the nature of cross-market trading interaction among precious metals is time-varying, and is conditional on the state of the economy in conjunction with the extent of each metal's industrial usage.

Our paper proceeds as follow. The methodology and estimation are outlined in section 2. The results are reported in section 3. Section 4 concludes.

2 Background and methodology

2.1 Backing out implied convenience yields

Our daily sample runs from January 1996 to July 2010, or 3,451 daily observations over 14.5 years. We only includes observations when TOCOM, LBMA and LPPM are open for trading. Our sample period straddles notable financial events such as the Asian Financial Crisis (AFC), Dot-Com Crash (DCC) and Global Financial Crisis (GFC). We partition our sub-samples into periods corresponding to normal versus adverse economic conditions.

TOCOM was established on 1^{st} Nov 1984 from the merger between the rubber, textile and gold exchanges. Daily data is downloaded directly from the TOCOM website. The files contain open, high, low, closing prices (afternoon session), volume and open interest for all contract cycles. Our futures market sample is constructed using the most heavily traded contract cycle. Unlike US or UK futures markets, trading activity in Japanese commodity futures are clustered on the most deferred contract[8]. We present contractual specifications for the four TOCOM precious metal contracts in Table 1[9] We use open interest data as a proxy to isolate on the range of dates when most traders would roll-over their futures positions. This is indicated by a sudden drop in the open interest of the most deferred contract and a simultaneous increase in the open interest of the next most deferred contract. The switching phenomenon on TOCOM tends to occur around the middle of every odd month, and it is consistent across all four precious metals[10]. We nominate the 15^{th} of every odd month as the switch date to piece together a continuous time series of observations.

INSERT TABLE 1

For commodities, it is often a challenge to justify or even identify a centralized spot market. The physical trading often occurs over-the-counter, where specific terms are not standardized e.g. pricing mechanism, quantity, grade, delivery dates etc. Fortunately for precious metals, global spot prices are heavily influenced by daily price fixings set by the LBMA for Gd and Si, and by the LPPM for Pl and Pd. The LBMA is a London-based trade association that embodies the wholesale over-the-counter market for gold and silver

[8] Webb (1995) suggests this is due to Japanese speculators allowing more time for their longer maturity contracts to become profitable.

[9] We exclude the sample period 24-Feb-2000 to 31-Mar-2000 due to a trading halt issued by TOCOM on its palladium contracts. The year 2000 witnessed a dramatic spike in the prices of palladium due in part to delivery interruptions from Russia creating a shortfall in supply. Prices were frozen to allow an orderly liquidation of contracts (See Hilliard, 2000). From the Dec 2010 contract onwards, the contract size for Si is reduced from 30kg to 10kg per contract. The tick size is also increased from 0.1 Yen/10g to 0.1 Yen/g from the Dec 2010 contract onwards.

[10] For example, trading interest in the Gd contract in early Mar 2006 centers on the Feb 2007 contract. Around mid-Mar 2006, open interest in the Feb 2007 contract started to decline sharply, but this is accompanied by the surge in open interest in the new Apr 2007 contract.

in London. The significant rise in Gd and Si prices in the 1980s, strengthened by the oil price inflation, resulted in extensive foreign interest and global reliance on the LBMA for price discovery. Driven by growth and financial deregulation, the LBMA was formed on 14 December 1987. London platinum quotations was introduced in 1973, with palladium quotation to follow shortly after. The London Platinum and Palladium quotations were upgraded to full fixings in 1989.

The LBMA and LPPM jointly provides a set of transparent and globally recognized benchmark prices for standardized grades of {Gd, Pl, Pd, Si}. The price fixings are set twice a day at 10:30 and again at 15:00 London time by a Fixing Board that is made up of principal members of the association[11]. For S_{it}, we use the morning price fixings to reduce the time zone differential between S_{it} in London and F_{it} in Japan. The price fixing mechanism is similar to a batch-auction system, where interim prices are adjusted until all buy and sell orders are matched, after which all orders are transacted at the fixed market clearing price[12].

We use the Bank of England official bank rate as our proxy risk free rate r_f. Since p_{it} are quoted in British pounds and F_{it} are in Japanese Yen, we use the GBP/Yen daily exchange rates from OANDA[13] to convert F_{it} from Yen to GBP. Lastly, for storage cost u, we use the 0 43%pa management fee charged by ETF Securities Ltd on their value-weighted average Physical Precious Metal Basket ETF. Listed on the Australian Securities Exchange, this ETF is backed by physical holdings of all four precious metals that are held by the designated custodians. The legal form of this are redeemable preference shares that constitute property rights to the physical holdings.

[11]This includes commercial banks, fabricators, miners refiners, transport companies and brokers etc.

[12]For example, the LBMA Gold Fixing Board comprises five fixing members. Orders are placed through the dealing rooms to the Gold Fixing Board members. The orders are netted, prices are adjusted and communicated back to the dealing room representatives. A next round of orders are collected and reviewed. This process continues until a market-clearing price is obtained.

[13]OANDA is a large Internet-based foreign exchange trading and currency service firm.

2.2 Trading variables and sub-sample analysis

Our key variables are return $r_{it} = Ln(\frac{p_{it}}{p_{it-1}})$, volatility $\sigma_{it} = |r_{it}|$ and Yen-denominated volume v_{it} i.e. turnover volume. The latter facilitates a comparison between different contract sizes[14] due to differences in contract size[15] For robustness, our volatility analysis incorporates a set of different measures. We focus only on findings that are robust across different measures. In addition to $\sigma_{it} = |r_{it}|$, we also consider the range-based measures of Parkinson (1980) and Garman and Klass (1980), which incorporates open (O_{it}), high (H_{it})and low (L_{it}) prices. These measures are jointly presented in equation (2).

$$
\begin{aligned}
\sigma_{it}^{Park} &= \sqrt{Ln(\frac{p_{it}^{h}}{p_{it}^{l}})^2/4Ln(2)} \\
\sigma_{it}^{GK} &= \sqrt{\frac{1}{2}Ln(\frac{p_{it}^{h}}{p_{it}^{l}})^2 - (2Ln(2)-1)Ln(\frac{p_{it}}{p_{it}^{o}})^2}
\end{aligned}
\tag{2}
$$

Augmented Dickey Fuller tests confirm that all price variables are I(1) stationary while all volume variables are I(0) stationary.[16] The time-series for cy_{it} across all four metals are also found to be stationary. A time-series plot of Gd and Pl futures prices in Figure 1 shows that the relative price movement between the two precious metals is affected by the DotCom crisis in May 2000, and more substantially, by the GFC in Sep 2008. During both crises, there is a breakdown of price co-movements between the two metals, with the price of Pl surging relative to Gd.

INSERT FIGURE 1

Accordingly, a sub-sample analysis that distinguishes between normal versus crisis economic periods constitutes an important aspect of our analysis on cross-market trading interactions among the four precious metals. However, it remains an open question as to how we

[14]We consider two volume measures by scaling the daily number of commodity i contracts traded by p_{it} and the mid-point between high and low prices for day t. As main results are stable across both volume measures, we report results based on volume scaled by p_{it}.

[15]For example, the Gd contract size is 1kg while for the Pl contract, it is 0.5kg.

[16]ADF test statistics and details of lag specifications for each variable are available upon request.

ascertain the start and end date for each of the three crises: AFC, DCC and GFC. The start of a financial crisis is generally associated with some cataclysmic events e.g. the collapse of the Thai Baht that sparks the AFC; Lehman Brothers collapse and the onset of the GFC. It is potentially problematic to specify and justify the end date for a financial crisis. In Table 2, we identify major ‘headline’ events covered by the financial media associated with the each of the three crises.

INSERT TABLE 2

We designate 02-Jul-1997, the day when Thailand devalues the Baht, as the start of the AFC. When the Dow Jones Index closes above 10,000 points on 29-Mar-1999, we assume that the global economy has returned to normal trading conditions. We set 01-May-2000 as the start of the DCC, when the NASDAQ fell sharply from its all-time high of around 4,800 points, as shown in Figure 2A. We associate 20-Jan-2002 as the recovery from the DCC, when Amazon announced its first-quarter profits. Lastly, the collapse of Lehman Brothers on 14-Sep-2008 is commonly perceived as the trigger that turned the US sub-prime crisis into a GFC. We can also see from Figure 2B that the Treasury Euro-Dollar spread and US 3-month LIBOR rate became extremely volatility shortly after the collapse of Lehman Brothers. We denote 31-Dec-2009 as the recovery phase, which is associated with increasing trends in the major stock market indices around the round.

INSERT FIGURE 2

In Figure 2C, we plot the cumulative return on the S&P 500, Nikkei 225 and FTSE 100 indices using the start of our sample as the base date. The graphs show that our designated sub-samples for the DCC and GFC correspond to overall declines across all three market indices of the major global economies. For the AFC, only the Nikkei 225 exhibited a downward trend. This suggests that the AFC is more of a regional crisis rather than a global crisis.

We complement our sub-sample analysis with a series of rolling window VAR estimations to track the t-stats of cy_{it} over time. In particular, we focus on whether the explanatory power of cy_{it} for Gd and Si fluctuates in opposite directions as our estimation window enters and exists each of the three financial crises. The results should offer further insights into the nature of time-varying information content of cy_{it} for different precious metals during normal versus crisis time periods.

2.3 Vector Autogressive (VAR) Estimation

We apply VAR estimation to analyze $\{r_{it}, \sigma_{it}, v_{it}\}$ interactions among the {Gd, Pl, Pd, Si} futures markets. We focus on futures trading activity since volume data is available. In subsequent work, we shall extend our analysis to the $\{r_{it}$ and σ_{it} using LBMA and LPPM prices. Our analysis is conducted sequentially over three rounds of VAR estimation for $i, j = \{Gd, Pl, Pd, Si\}$.

First, we estimate a four-equation VAR using cy_{it} for the four metals in equation (3). This allows us to examine the relative influence that the cy_{it} of one metal exerts onto another.

$$cy_{it} = \beta_{0i} + \sum_{j} \sum_{s=1}^{S} \beta_{1ijs} cy_{jt-s} + u_{it} \tag{3}$$

Second, we separately estimate four sets of four-equation VAR that comprises $\{cy_{it}, r_{it}, \sigma_{it}, v_{it}\}$, one for each of {Gd,Pl,Pd,Si}. Our aim here is to examine the extend of each metal's cy_{it} on its own-market trading activity.

$$\begin{aligned}
cy_t &= \delta_{01} + \sum_{s=1}^{S} (\delta_{1s} cy_{t-s} + \delta_{2s} r_{t-s} + \delta_{3s} \sigma_{t-s} + \delta_{4s} v_{t-s}) + u_{1t} \\
r_t &= \alpha_{02} + \sum_{s=1}^{S} (\alpha_{1s} cy_{t-s} + \alpha_{2s} r_{t-s} + \alpha_{3s} \sigma_{t-s} + \alpha_{4s} v_{t-s}) + u_{2t} \\
\sigma_t &= \beta_{03} + \sum_{s=1}^{S} (\beta_{3s} cy_{t-s} + \beta_{3s} r_{t-s} + \beta_{3s} \sigma_{t-s} + \beta_{2s} v_{t-s}) + u_{3t} \\
v_t &= \gamma_{04} + \sum_{s=1}^{S} (\gamma_{4s} cy_{t-s} + \gamma_{4s} r_{t-s} + \gamma_{4s} \sigma_{t-s} + \gamma_{2s} v_{t-s}) + u_{4t}
\end{aligned} \tag{4}$$

Lastly, we separately estimate three sets of eight-VAR to examines the interactions between the cy_{it} and each of $\{r_{it}, \sigma_{it}, v_{it}\}$ across all four metals. Our focus is on whether the lagged cy_{it} of one precious metal Granger-causes the trading variable of another, especially r_{it} and/or σ_{it}, and whether such incremental information, if present, varies over time conditional on normal versus crisis economic conditions. Any positive findings we have on r_{it} or σ_{it} possess practical relevance for trading and hedging applications respectively.

$$\begin{aligned} cy_{it} &= \delta_{0i} + \sum_{j}\sum_{s=1}^{S}(\delta_{1ijs}cy_{jt-s} + \delta_{2ijs}\sigma_{jt-s}) + u_{1it} \\ \sigma_{it} &= \beta_{0i} + \sum_{j}\sum_{s=1}^{S}(\beta_{1ijs}cy_{jt-s} + \beta_{2ijs}\sigma_{jt-s}) + u_{2it} \end{aligned} \tag{5}$$

We perform the usual diagnostic tests to determine the optimal lag specification (S) for each of the VAR specifications. This is a vital consideration since VAR estimates, which constitute our main results, are sensitive to the specified lag structure. We use the Schwarz Information Criterion (SIC) to identify specific lag structures. From there, we perform both lag-exclusion F-tests and likelihood ratio tests to determine an optimal S for each VAR estimation.

3 Empirical Results

3.1 Preliminary results

In Figure 3, we present the price plots S_{it} and F_{it} for each of the four metals. The pair of prices for each metal show near-synchronous movements over time. It also appears that Gd, Si and Pd share similar price patterns, while Pd only display co-movements with Pl in the last few years of our sample. Lastly, it is also apparent that the four metals are all affected by the GFC.

INSERT FIGURE 3

We plot the time series of cy_{it} in Figure 4. Consistent with Figure 3, the graphs show similar fluctuations in the cy_{it} for Gd, Pl and Si. It is also interesting to note that Pd and Si display negative cy_{it} more often than Gd and Pl. Since Si and Pd have substantially heavier industrial usage than Gd and Pl, manufacturers sometimes find it inconvenient to hold physical stock e.g. when their industry is experiencing a downturn.

INSERT FIGURE 4

We report descriptive statistics for key variables in Table 3. Panel A figures are based on the full sample, while those in Panel are based on the GFC sub-sample. The comparison allows us to ascertain if the GFC has induced a structural break in the data for precious metals.

The summary statistics of cy_{it} between the two panels confirms that cy_{it} has experienced a GFC-related structural break. The mean cy_{it} for all four metals is positive in both Panels A and B. However, the mean cy_{it} values are lower in the GFC sub-sample, but with noticeable increases in the volatility of cy_{it}. In Panel A, Pl has a larger mean cy_{it} than Gd. But in Panel B, it is Gd that has a larger mean cy_{it} than Pl. This is consistent with our argument that during a credit-constraint financial crisis, manufacturers, especially car-makers, are liquidating their holdings of Pl for cash. Si has a lower mean cy_{it} than Pl and Pd in Panel, but Si has the highest mean cy_{it} in Panel B. Since Si has the highest industrial usage and the cheapest among the four precious metals, it remains convenient to hold Si during the GFC relative to Pl and Pd.

INSERT TABLE 3

The two panels also reveal a substantial increase in the return volatility of all four metals. Pd has the highest volatility while Gd had the lowest volatility of the four precious metals. This is consistent with the argument of Sari et.al (2010) of a large stockpile of gold available, although mostly held in the vaults of reserve banks. In addition, due to its safe-haven status gold, there is substantial trading liquidity in gold markets. As such, there is a smaller tendency for gold markets to display excessive volatility.

INSERT TABLE 4

We report correlation coefficients between key variables in Table 4. The r_t among the various precious metals are all highly correlated. The highest is between Gd and Si at 0.78, while the lowest is between Si and Pd at 0.53. The cy_{it} for Gd is positively correlated with the cy_{it} of the other three metals. Interestingly, the cy_{it} for Gd is negatively correlated with the r_t of all four metals. In stark contrast, the cy_{it} for Si has a small positive correlation with the r_t of Gd (0.086), Pd (0.095) and Si (0.133).

For unit root tests, we use the Dickey and Fuller (1979) and Phillips and Perron (1988) tests. In addition, we also use the Dickey-Fuller GLS-detrend unit root tests advocated in Sari et al (2010). We include an intercept and time-trend for testing r_{it}. For σ_{it}, we include only an intercept since there is no reason to believe precious metals are becoming more volatile over time. We include an intercept for v_{it}. Lastly, for cy_{it}, we include an intercept in our stationary tests. The descriptive statistics in Table 3 and the cy_{it} time-series plots in Figure 4 strongly suggests that cy_{it} for all four metals have zero means. The tests confirm that cy_{it} is stationary.

3.2 Main Results

In this section, we present and discuss the three sets of VAR estimations: i) VAR on cy_{it}; ii) VAR on own-market trading variables and iii) VAR on cy_{it} and each trading variable across all markets.

3.2.1 VAR estimation on cy_{it}

Impulse response functions from VAR estimations reveal the adjustment process of each variable to exogenous shocks that enter the system. We examine the impulse response functions from VAR estimations on cy_{it}, which provides a good indication of the direction and magnitude of one metal's cy_{it} on another i.e. the relative influence of each metal s cy_t across all four metals. Sari et.al (2010) suggest that the generalized impulse response approach has an advantage over the orthogonalized approach, which is sensitive to the ordering of variables in the VAR equations. However, the interpretation of the generalized impulse response functions is not straightforward due to non-zero covariances between the components. We employ the Cholesky one standard deviation decomposition impulse response functions to transform the innovations as to allow the resulting components to be uncorrelated. We also results of the generalized approach as a robustness check.

INSERT FIGURE 5

We present the impulse responses functions in Figure 5, which shows the size of the initial shock and the rate of dissipation by each variable in the VAR estimation. The graphs on the diagonals show that Pl's cy_{it} is the most efficient, since most of an exogenous shock is dissipated within 10 lags. For Gd and Si, portion of the initial shocks remain even after 10 lags. The cy_{it} of Pd appears the least efficient, with shocks persisting even after 10 lags. In the off-diagonals, the cy_{it} of Gd seems to be the only variable exerting a cross-market influence on the cy_{it} of Pl and Si. And in both cases, the shock persist even after 10 lags.

To confirm the influence of Gd's cy_{it} that is suggested by Figure 5, we compute and plot the variance decomposition functions in Figure 6 across four panels. These panels correspond to each of the three crises as well as the normal period in between the DCC and GFC. The forecast error variance decomposition demonstrates the relative importance of the effects of unexpected innovations of the cy_{it} of Gd on the cy_{it} of the other three metals.

INSERT FIGURE 6

The cross-market influence of Gd's cy_{it} is clearly shown in both Panel B (DCC) and Panel D (GFC). In stark contrast, Panel C shows that the influence of Gd's cy during normal economic times is comparatively subdued. This finding is consistent with Figure 5 and it also confirms our argument that the convenience of gold is elevated during periods of financial turmoil. The results are not evident for Panel A (AFC). We noted earlier that it is arguable whether the AFC has the same impact on the global economy compared to the DCC and GFC.

We present the VAR(4) estimation results in Table 5 Panel A for the full sample, Panels B and C for the AFC and DCC, Panel D for the normal period, and lastly in Panel E, estimates for the GFC.

INSERT TABLE 5

The influence of lagged cy_{it} for Gd on Si and Pl is significant and generally robust across four sub-samples. As supported by the variance decomposition in Figure 6, the t-statistics of Gd's cy_{it} increases during the DCC and GFC sub-samples. The cy_{it} of Pl also display some cross-market explanatory power, albeit less substantial than Gd. While this is also true for the cy_{it} of Si, its influence is not robust across sub-samples. Specifically, its cross-market influence on the other three metals is not evident during the crisis sub-samples. The strongest evidence of the cross-market influence of Si's cy is found in in Panel D i.e. during normal economic times. Pd has the least cross-market influence on the other metals. However, the cy_{it} of Pd affects the cy_{it} of Gd and Si, but only during the GFC in Panel E.

In sum, the VAR results on cy_{it} suggest that Gd is the most influential. This is followed by Pl and Si. The cy_{it} of Pd has the least cross-market influence.

3.2.2 Own-market VAR estimation

We ask the question whether incremental information is contained within the implied convenience yield data series, and whether this information manifests in the return, Yen-denominated volume or volatility series of its own market. The convenience yield is now included in a multivariate VAR model to analyze the incremental information. Like previous, we also included sub sample and full sample analysis to highlight any time-varying behavior, especially with crisis and non-crisis periods.

INSERT TABLE 6

The results are reported in Table 6. Using a VAR 4 multivariate analysis model, the influence of lagged cy_{it} of Gd is analyzed its own-market r_t, σ, v_t. Lagged 1 to 3 cy_{it} for Gd possess significant explanatory power on r_t for the full sample. However, the finding is not robust across sub-samples. Analysis suggests that this is identified in the full sample, AFC and Interval sub samples, however notably absent in the DCC and GFC. The incremental information of the convenience yield of gold manifests during these periods is identified in the absolute volatility series with a significant increase in lags 1 and 4 during the GFC.

The VAR specification results report that the impact of the AFC is quite different to that of the DCC and GFC. This result was somewhat surprising, however on reflection it is important to note that the AFC was primarily a currency crisis and whilst the heart of this crisis in South East Asia is geographically closer to the TOCOM , our results indicate that the AFC did not have the same crisis impacts of the DCC and GFC. The results infer dominance on U.S and other global markets over than the domestic market. This result is consistent with cross-market linkages between the lead of information flows from the U.S to the Japanese precious metals future trading as shown by Xu and Fung (2005).

As a robustness check for volatility measurements, the Garman-Klass volatility series was also included and results reported in Table 6. The volatility measurement of Garmin and Klass in our sample failed to support the increase in influence of convenience yield on the volatility series as noted in the GFC. The Garman-Klass volatility measure utilizes the open price in its estimation and can be influenced by market microstructure issues. Due to this discrepancy, further volatility measures (high - low measure, and Parkinson (1980) measure) were included in the VAR specification, with results (p=0.05) that supports our initial volatility measure.

The incremental information of Pl's convenience yield manifests in a lag 1 (p=0.05) significant explanatory variable in the return series. This occurs in full sample and subsamples with exception to the GFC. The GFC corresponded to compounding factors of decreased industrial demand, liquidation of inventory and the U.S 'cash for clunkers' program that also increased supply of Pl from recycling, which led to the dramatic price decrease. The incremental information of the convenience yield during the GFC subsample is noted in the volatility series lag 1. Pl's convenience yield series incremental information is also directed to the Yen-denominated volume series in the interval subsample only. The results suggest that the informational content of Pl's convenience yield series manifests in 1) return and volume series in normal trading conditions, 2) return series in crisis periods, 3) volatility in extreme crisis periods.

The informational content of cy_{t-1} for Si is significant on r_t for the full sample. Sub sample analysis shows this result is absent in the GFC and whilst present for the AFC, DCC and Interval sub sample periods, declines in the times of crisis. Interestingly the lags 1, 2, and 3 of the cy_{it} of Si are significant in the interval sub sample, however lag 1 is significant and positive (t test = 12.196, p= 0.05) and lags 2 and 3 are significant and negative (lag2 t test = -2.5, p=0.05, lag 3 t test = -2.6, p=0.05). This finding tends to support overreaction and re-adjustments in traders activities and provides some support for behavioral finance (i.e. herding behavior) theories in commodities markets. Incremental information of the volatility series by the convenience yield is significant at lag-4 cy_{it} for Si with increases in the t-test statistic evident in times of crisis.

The informational content of Pd's cy lags is restricted to the short run (lag 1 and 2) on the return series, which is found to robust across the sub sample analysis. Whilst the strength of this finding decreases in the GFC (t test = 1.85 p=0.1) and the AFC (t test = 2.96, p=0.05), there does not seem to be a strong distinction between DCC crisis and non crisis period. This result is indicative of the Russian supply uncertainties that coincide with this sub sample period and also explains the convenience yield lag 1 and 2 significance on the Yen denominated volume during this sub sample. Cy Pd (-1) is significant for the volatility VAR estimation. The results for palladium indicate the incremental information of Pd's convenience yield manifest in the return and volatility series in periods of normal trading conditions.

3.2.3 VAR estimation of cy_{it} on return and volatility

Here we test if the influential cy_{it} of Gd and Si offer explanatory power over cross- market interactions and whether this information varies across normal and crisis time periods. Due to space constraint, we report only VAR estimates for volatility. The results are presented in Table 7.

INSERT TABLE 7

The lag-1 cy_{it} for Gd is significant in the Si r_t and it is robust across the full sample, DCC, Interval and GFC, with an exception during the AFC. During normal trading conditions as determined by the interval subsample, the lag cy Gd(-1) lag cy Gd(-3) lag cy Gd(-4) are significant to the p=0.05 confidence interval. Monitoring the t- test statistic over the sample period demonstrates a greater t-test value in normal trading conditions and a significant decrease during times of crisis. The cy Gd(-1) is also significant for the return of the Pl and Pd series during the AFC and Interval sample periods, and notably insignificant in the crisis times of DCC and the GFC. This short run information content relationship deteriorates in times of crisis reflecting the industrial and precious applications of platinum and its poor cousin palladium compared to the precious and monetary safe haven of gold.

The preferences of Gd over Pl in times of crisis are appreciable by the dichotomy of platinum's industrial demand decreasing and in turn its precious metal status declining. Interestingly the cy Si(-1) is significant in predicting the return series for the three precious metals in the full sample. In the sub sample analysis we report that this is primarily restricted to the interval period. Si's lag 1, the most industrious of the precious metal group information content is restricted to normal economic trading conditions and deteriorates in crisis periods. As cy Si(-1) is significant for the return series of Gd, and cy Gd(-1) is significant for the return series of Si the presence of bi-directional information transmission between these markets is established.

INSERT FIGURE 7

Using the integer of the t-test statistic as a proxy of information content of the convenience yield it is apparent that the convenience yield of silver offers more incremental information in normal trading conditions, about the returns of all the precious metals then does gold, the most liquid of the four. The liquidation of stockpiles of platinum and palladium from industry and a simultaneous flight to safe haven assets such as gold may go some way to explain the breakdown of this finding in times of crisis.

This finding indicates that the use of both the lags of Gd and Si convenience yield could be incorporated in a trading strategy to offer abnormal returns. As our results are dependant of the coarse subsamples as defined in the empirical specifications, for robustness we employ 20 quantile estimation VAR and track the changes in the t-test statistics.

INSERT FIGURE 8

As shown in Figure 7, the cy Si(-1)is robust for the returns of Gd and Si, however results are not as robust for Pd and Pl across the time period that consists of the interval sub sample

(2003 - 2008). The finer estimations fail to support the coarser sub samples for the cyGd-1 results. Further research using a moving window VAR estimation routine may provide clearer delineation across the time series. 4.6.1 Influential convenience yields incremental information on cross markets trading of precious metal volatility series. We report the influence of Gd convenience yield lags 1,3,4, Pl's convenience yield lags 1,3,4, Si's convenience yield lags 1,2,3,4 and Pd's convenience yield lags 1 and 4, on the volatility of Gd at time t, during the GFC.

The liquidation of inventory levels of platinum and palladium for free cash in the times of crisis and a slowdown of industrial production during the GFC proceeds the volatility of GD. Whilst some of the cash liquidated may end up in Gd reserves, we expect that the information transmission is not a direct link and that both are reacting to the simultaneous slowdown of industrial production and flight to quality from fund managers and investors. Using the coarse subsample estimation, the convenience yield of Gd offers no significant information content of the volatility of Pl, Pd, and Si.

We utilise the 20 quantile VAR estimation routine introduced above for the volatility series with a notable increase in the t-test statistic of the convenience yield of Gd lag 1 and 4 for the precious metal volatility series in Figure 8. This feature is averaged in the coarser sub sample originally introduced in the earlier empirical specifications. The information content of the Gd convenience yield on the volatility series appears to be a short run relationship in times of crisis, and may represent an unwinding of safe haven asset allocations and replenishment of inventories as productivity levels start to increase. This short run property is consistent with the short run safe haven results as reported by Baur and Lucey (2010).

4 Concluding remarks

We confirm that the daily implied cy_{it} extracted from cost-of-carry provides incremental information to its own-market r_{it}, σ_{it} and/or v_{it} series. While the extent of the significance of cy_{it} differs across precious metals, the overall finding is consistent and suggests that lagged cy_{it} provides incremental explanatory power to trading variables over their own lagged variables. In cross-market analysis, we confirm that the more influential cy_{it} of Gd and Si also affects the return and volatility processes of other precious metals. More importantly, we can confirm that the relative influence of Gd and Si's cy_{it} varies over time conditional on whether the global economy is in a normal or crisis state.

Gd is convenient to hold as a storage of value in times of financial turmoil due to its safe-haven status. In stark contrast, Si is the cheapest of the four precious metals, and since it carries the heaviest industrial usage, Si is convenient to hold during normal economic times. Our finding confirms that the cy_{it} of Si is the most influential in the return equations of all precious metals during normal economic times. Gd's cy_{it} is short-run influence on the σ_{it} of other precious metals during crisis periods. The implication of our findings is twofold. First, incorporating the cy_{it} of Si into return-based trading strategies for Gd could yield incremental profits. The caveat is that this tend to work better during normal economic times. Second, incorporating the cy_{it} of Gd into volatility prediction of the other three precious metals may be economically significant. However, this may work only during times of financial turmoil. Both issues constitute avenues for future research.

References

[1] Baur, D., Lucey, B., 2010. Is Gold a hedge or a safe haven? An analysis of stocks, bonds and gold. Financial Review 45, 217-229.

[2] Brennan, M., 1958. The supply of storage. The American Economic Review 48, 50-72.

[3] Chen, N., Roll, R., Ross, S., 1986. Economic forces and the stock market. The Journal of Business 59, 383-403.

[4] Chen, T., Chung, H., Lin, Y., 2008. The information content of the implied convenience yield: Using American call option based structural model. SSRN working paper series http://ssrn.com/abstract=957621

[5] Dincerler, C., Khokher, Z., Simin, T., 2005. An empirical analysis of commodity convenience yields. SSRN working paper series http://ssrn.com/abstract=748884

[6] Draper, P., Faff, R., Hillier, D., 2006. Do precious metals shine? An investment perspective. Financial Analysts Journal 62, 98-106.

[7] Escribano, A., Granger, C., 1998. Investigating the relationship between gold and silver prices. Journal of Forecasting 17, 81-107.

[8] Fama, E., French, K., 1986. Business cycles and the behavior of metals prices. Journal of Finance 43, 1075-1093.

[9] Fluros, C., 2009. Modeling volatility using high, low, open and closing prices: Evidence from four S&P indices. International Research Journal of Finance and Economics 28, 198 -206.

[10] Frank, M. Stengos, T., 1989. Measuring the strangeness of gold and silver rates of return. Review of Economic Studies 56, 553-567.

[11] Garman, G., Klass, M., 1980. On the estimation of security price volatilities from historical data. Journal of Business 53, 67-78.

[12] Hamilton, J., 1989. A new approach to the economic analysis of nonstationary time series and the business cycle. Econometrica 57, 357-384.

[13] Hamilton, J., 1990. Analysis of time series subject to changes in regime. Journal of Econometrics 45, 39-70.

[14] Heaney, R., 2006. An empirical analysis of commodity pricing. Journal of Futures Markets 26, 391-415.

[15] Heinkel, R., Howe, M., 1990. Commodity convenience yields as an option profit. Journal of Futures Markets 10, 519-533.

[16] Heinkel, R., Howe, M., Hughes, J., 1990. Commodity convenience yields as an option profit. Journal of Futures Markets 10, 519-533.

[17] Hill, R., Griffiths, W., Lim, G., 2008. Principles of econometrics, J.W Wiley 3rd Ed.

[18] Jaffe, J., 1989. Gold and gold stocks as investments for institutional portfolios. Financial Analysts Journal 45, 53-59.

[19] Jarrow, R., 2010. Convenience yields. Review of Derivatives Research 13, 25-43.

[20] Scheinkman, J., Schectman, J., 1983. A simple competitive model with production and storage. Review of Economic Studies 50, 427-441.

[21] Kaldor, N., 1939. Speculation and economic stability. Review of Economic Studies 7, 1-27.

[22] London Bullion Market Association, 2008. A guide to the London Precious Metals Markets LBMA and LPMA.

[23] Liu, P, Tang, K., The Heteroskedasticity of the Commodity Convenience Yield Working Paper Available at SSRN

[24] London Bullion Market Association, 2008. A Guide to the London Precious Metals Markets.

[25] Lucey, B., Tully, E., Poti, V., 2004. International portfolio formation, skewness, and the role of gold. IIIS discussion paper no. 30.

[26] Milonas, N., Thomadakis, S., 1997. Convenience yields as call options: An empirical analysis. Journal of Futures Markets 17, 1-15.

[27] Sari, R., Hammoudeh, S., Soytas, U., 2010. Dynamics of oil price, precious metal prices and exchange rate. Energy Economics 32, 351-362.

[28] Scheinkman, J., Schectman, J., 1983. A simple competitive model with production and storage. Review of Economic Studies 50, 427-441.

[29] Telser, L., 1958. Futures trading and the storage fo cotton and wheat. Journal of Political Economy Jun, 233-255.

[30] Xu, X., Fung, H., 2005. Cross-market linkages between U.S and Japanese precious metals futures trading. Journal of International Financial Markets, Institutions and Money 15, 107-124.

Figure 1: Gold and Platinum future prices on TOCOM (GBP) for the whole sample period

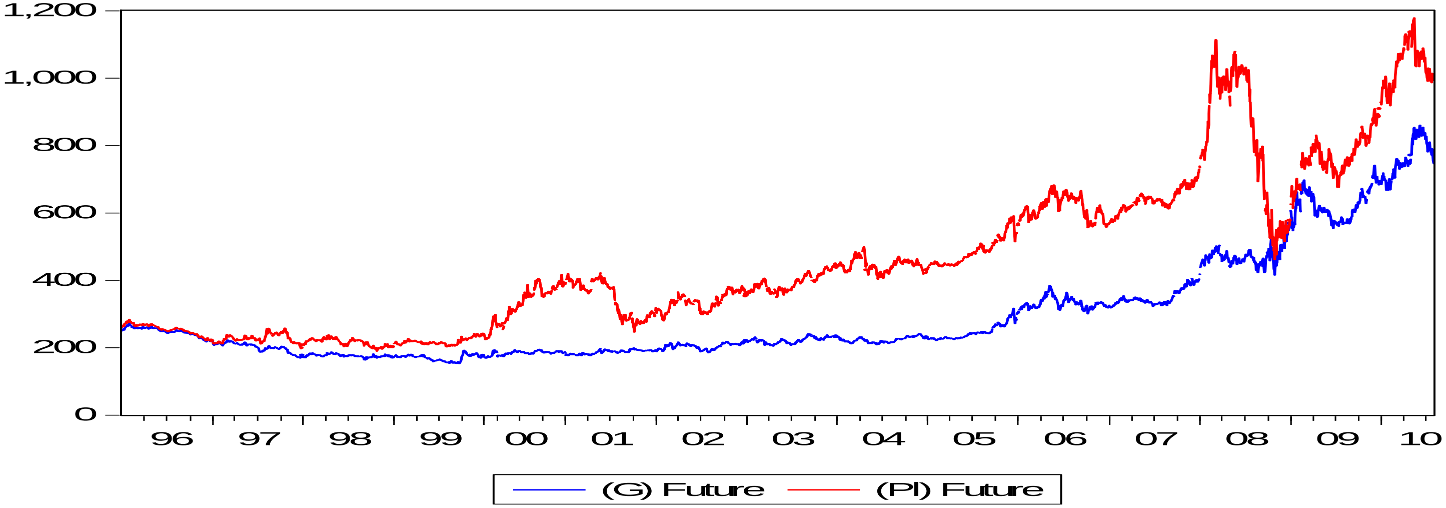


Figure 2A. NASDAQ 100 index for entire sample. Sample representing the DCC is shown as NASDAQ retreats from high in May 2000. (Source: CapitalIq 2010)

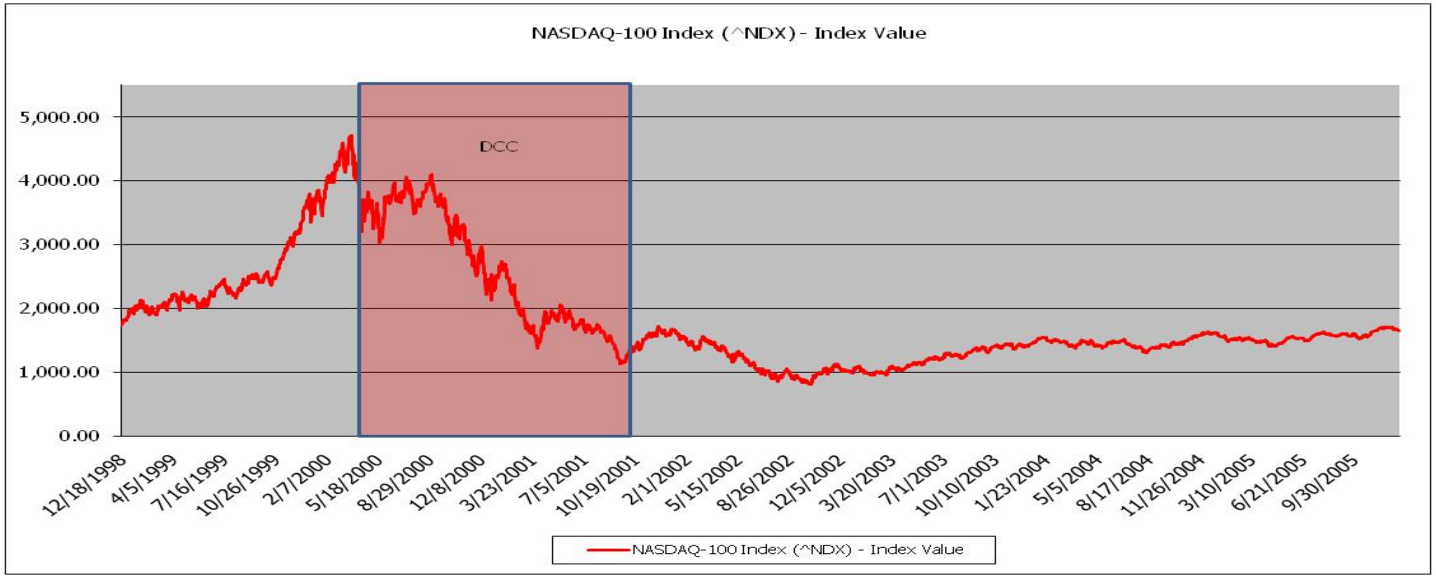


Table 2. Timeline of events to delineate crisis and non crisis subsamples

Sub-sample period	Sample range
•AFC (1997-1999)	•Thailand devalues Baht 02/07/1997 •Dow Jones closes above 10,000 29/03/1999
•DCC (2000 - 2002)	•NASDAQ comes off its all time highs May 2000 (01/05/2000) (see Figure 5) •January 2002 Amazon announces first quarter profit
•Interval (2003-2008)	•Normal Trading Period defined by 01/01/2003 01/08/2008.
•GFC (2008-2009)	•Sept 14th 2008 Lehman Brother Collapse. Overnight freezing of wholesale money markets (see TED spread – Figure 6) •31/12/2009. Arbitrary date to mark end of tumultuous 15-month period.

Figure 2B: TED spread September 2008. Graph demonstrates the overnight wholesale credit market freeze on the collapse of Lehman Brothers as represented by Treasury note euro dollar spread. This date is selected to represent the beginning of the GFC sub sample period. (Source: ChartMechanic)

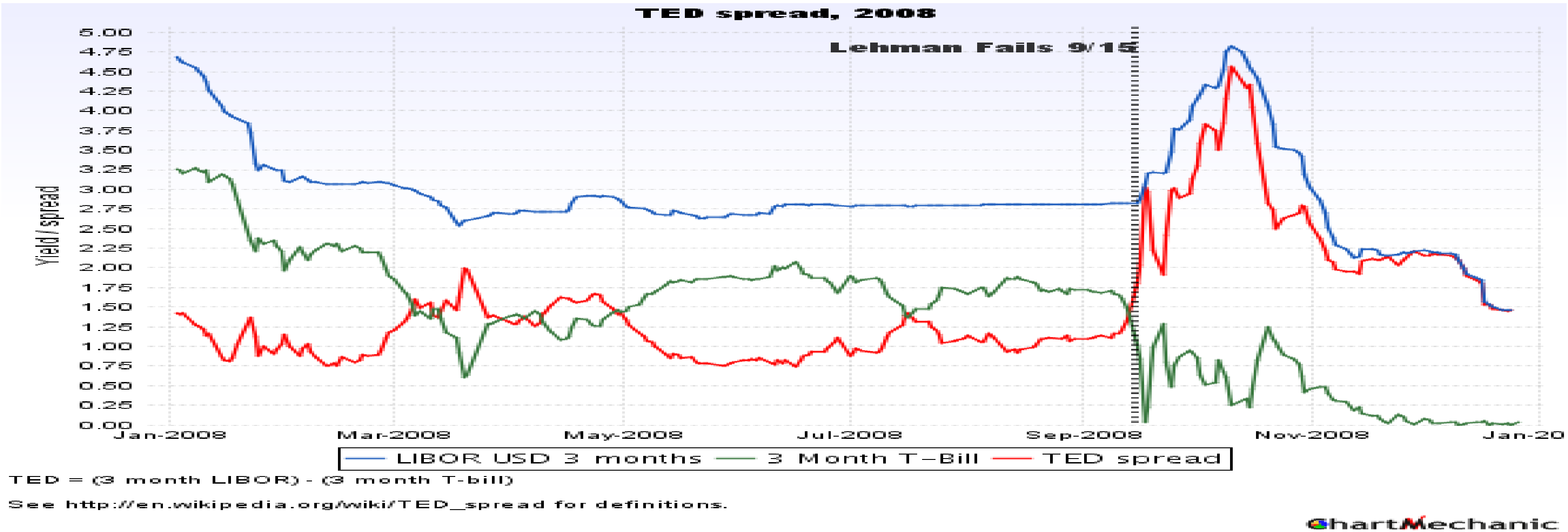


Table 1: Contract specification for Gold, Silver Platinum and Palladium futures as traded on TOCOM

	Gold	Silver	Platinum	Palladium
Date of Listing	March 23, 1982	January 26,1984	January 26,1984	August 3, 1992
Standard	Gold of minimum 99.99% fineness	Silver of minimum 99.99% fineness	Platinum of minimum 99.95% fineness	Palladium of minimum 99.95% fineness
Contract Unit	1 kg / contract (approximately 32.15 troy ounces)	30 kg / contract (approximately 964.53 troy ounces)(1/5 of standard contract)	500 g / contract (approximately 16.08 troy ounces)	500 g / contract (approximately 16.08 troy ounces)
Delivery Unit	1 kg	30 kg	500 g	3 kg (Delivery Unit = 6 Contract Units)
Minimum Price Fluctuation	JPY 1 per gram	JPY 0.1 per 10 grams	JPY 1 per gram	JPY 1 per gram
Customer Position Limit (for each long/short position)	**Commercials *1** **and investment funds *2:** Current contract month 10,000 contracts All contract months combined: 30,000 contracts	**Commercials *1** **and investment funds *2:** Current contract month 3,000 contract All contract months combined: 30,000 contracts	**Commercials *1** **and investment funds *2:** 1st contract month in an even month*3: 600 contracts 1st contract month in an odd month: 700 contracts 2nd contract month: 1,200 contracts All contract months combined: 10,000 contract	**Commercials *1** **and investment funds *2:** 1st contract month in an even month*3: 450 contracts 1st contract month in an odd month: 600 contracts 2nd contract month: 1,200 contracts All contract months combined: 9,000 contract
	Other customers All contract months combined: 5,000 contracts	**Other customers** Current contract month: 1500 contracts	**Other customers** 1st contract month in an even month*3: 100 contracts 1st contract month in an odd month: 150 contracts 2nd contract month: 200 contracts All contract month combined: 3500 contracts	**Other customers** 1st contract month in an even month*3: 60 contracts 1st contract month in an odd month: 120 contracts 2nd contract month: 240 contracts All contract month combined: 2500 contracts
Contract Months	All even months within a year (on the day when a New Contract Month is generated, there will be 6 even months starting from 2 months after the month which the said day belongs to)			
First Trading Day of New Contract Month		Day session on the business day following the Last Trading Day of the current contract month		
Last Trading Day		Day session on the third business day preceding the Delivery Day		
Final Settlement Day	N/A	N/A	N/A	N/A
Delivery Day	The last day of each even month *4	The last day of each even month *5	The last day of each even month *5	The last day of each even month *5
Trading Hours		Day session 9:00 - 15:30 (JST) Night session 17:00 - 23:00 (JST)		

Figure 5 Cy on Cy Impulse Response Functions for the precious metals Gd, Pl, Pd and Si.

One standard deviation innovations of cy_i to cy_i are shown

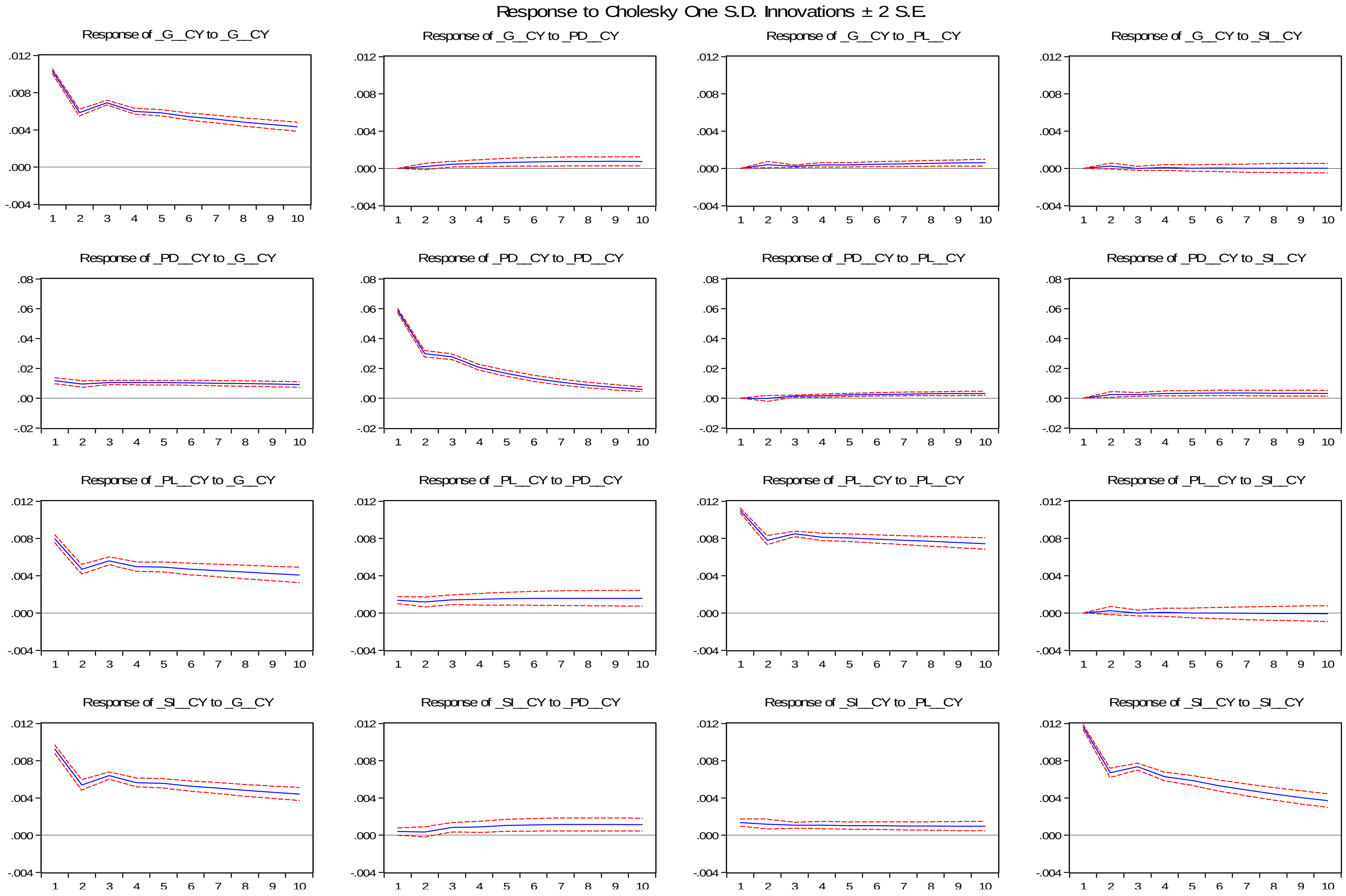


Figure 6 Variance Decomposition of Gd influence of Pd, Pl, Si across subsamples.

The influence of Gd as identified by the impulse response function in figure 4.1 is tracked across the sub sample time intervals of the AFC, DCC, interval period and GFC. Panel A represents AFC, Panel B the DCC, Panel C the interval period indicative of normal trading environment and Panel D the GFC

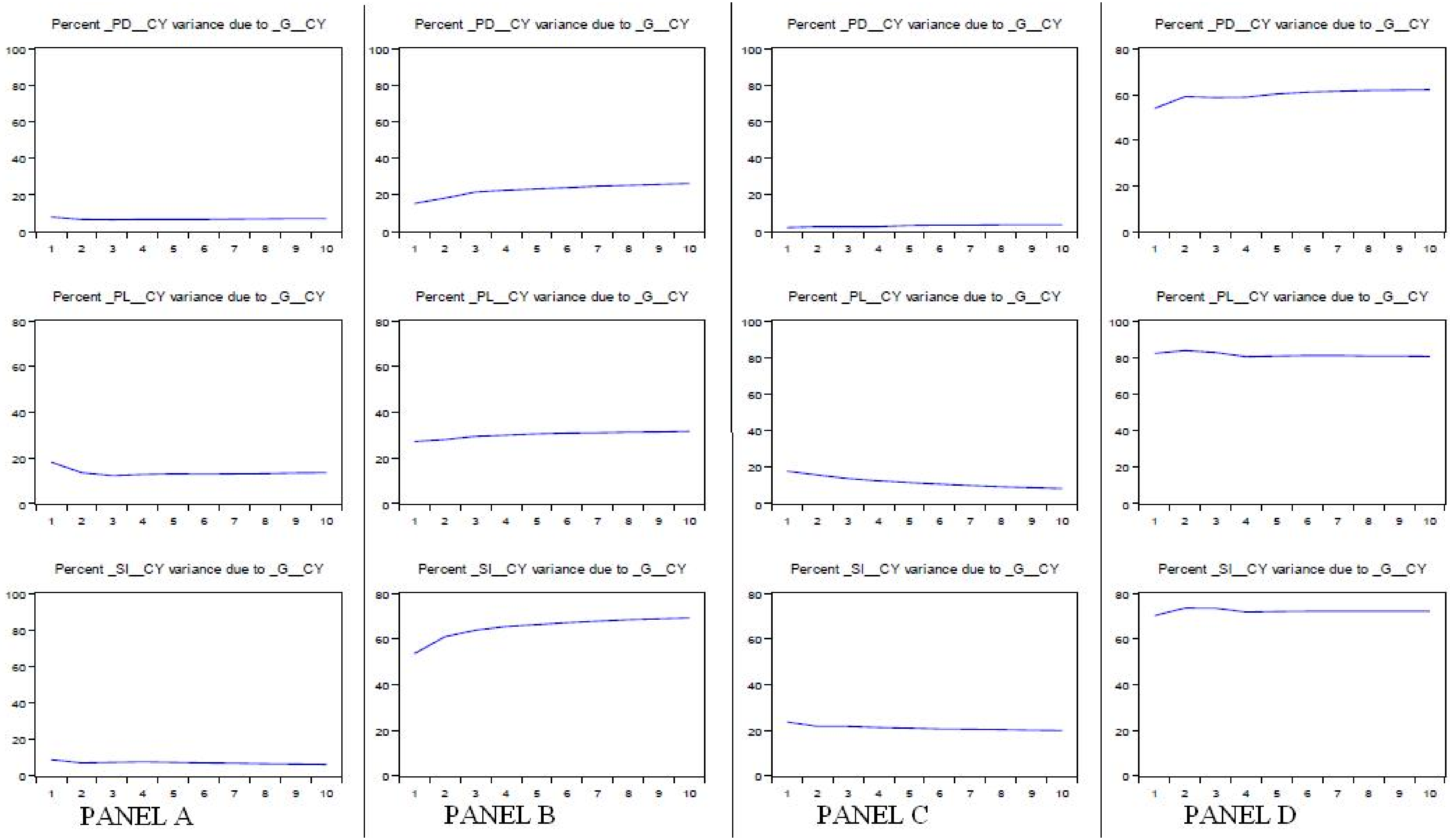


Table 5 VAR routine estimation for the cy against cy.

Results show t-test estimations (asterisks i[illegible] significance as per bottom of table) for full sample, ACC, DCC, Interval and GFC

Panel A — Full Sample

Full Sample	cy_{Gd}	cy_{Pd}	cy_{Pl}	cy_{Si}
$cy_{Gd(-1)}$	19.0026 ***	0.51956	-4.29775 ***	0.12967
$cy_{Gd(-2)}$	9.8724 ***	-0.71269	1.46725	2.54635 ***
$cy_{Gd(-3)}$	1.20601	0.71077	-0.39953	-1.37261
$cy_{Gd(-4)}$	7.72348 ***	0.74195	2.6058 ***	-0.7445
$cy_{Pd(-1)}$	0.0763	25.1591 ***	1.00098	-0.47694
$cy_{Pd(-2)}$	0.77027	4.52099 ***	1.2423	0.80851
$cy_{Pd(-3)}$	0.00166	10.2428 ***	-1.31981	-0.05501
$cy_{Pd(-4)}$	0.96137	4.45779 ***	-0.4169	1.20234
$cy_{Pl(-1)}$	2.21175 ***	0.23574	31.4117 ***	1.69682 **
$cy_{Pl(-2)}$	-1.05671	1.73555 **	6.98118 ***	-1.34284
$cy_{Pl(-3)}$	1.35056	-1.58897	2.4962 ***	0.63359
$cy_{Pl(-4)}$	-2.08295 ***	0.18627	4.13558 ***	-0.66335
$cy_{Si(-1)}$	0.20621	1.27764	0.1436	21.3425 ***
$cy_{Si(-2)}$	-3.03513 ***	-1.20971	-2.43999 ***	5.52948 ***
$cy_{Si(-3)}$	2.14248 ***	0.8999	1.80086 **	7.04316 ***
$cy_{Si(-4)}$	0.66815	0.92789	0.61622	7.54602 ***

Panel B — ACC

ACC	cy_{Gd}	cy_{Pd}	cy_{Pl}	cy_{Si}
$cy_{Gd(-1)}$	5.06575 ***	-0.96117	-3.1954 ***	-2.2359 ***
$cy_{Gd(-2)}$	4.94876 ***	0.4411	1.59054	2.23791 ***
$cy_{Gd(-3)}$	1.21869	1.11153	2.15904 ***	0.10361
$cy_{Gd(-4)}$	2.94269 ***	-1.01414	-0.70645	-0.98339
$cy_{Pd(-1)}$	-0.64643	14.5879 ***	-2.21821 ***	-1.0601
$cy_{Pd(-2)}$	-0.43138	1.61659	1.6623 **	0.42226
$cy_{Pd(-3)}$	-0.24618	-0.00721	-0.26598	0.71682
$cy_{Pd(-4)}$	1.40271	0.00089	-0.05149	-0.74986
$cy_{Pl(-1)}$	1.83292 **	-0.02298	13.2668 ***	1.81733 **
$cy_{Pl(-2)}$	-1.39141	0.51527	1.24757	-1.2408
$cy_{Pl(-3)}$	2.16056 ***	-0.35271	0.3953	0.03163
$cy_{Pl(-4)}$	-2.30614 ***	0.02237	1.05775	-0.14853
$cy_{Si(-1)}$	-0.70678	-0.17172	0.14509	12.1792 ***
$cy_{Si(-2)}$	0.44466	-0.0715	-1.10332	1.90089 **
$cy_{Si(-3)}$	-0.20018	-1.58686	-0.29761	1.01446
$cy_{Si(-4)}$	0.35661	3.359 ***	1.81985 **	2.40275 ***

Panel C — DCC

DCC	cy_{Gd}	cy_{Pd}	cy_{Pl}	cy_{Si}
$cy_{Gd(-1)}$	9.68064 ***	1.54207 ***	0.24332	3.9136 ***
$cy_{Gd(-2)}$	3.78602 ***	1.04591	1.02212	-0.67728
$cy_{Gd(-3)}$	-0.3042	-2.70837 ***	-1.39439	-1.51781
$cy_{Gd(-4)}$	1.29445	0.88579	-0.14684	-0.95457
$cy_{Pd(-1)}$	1.39874	12.8778 ***	0.13665	0.34397
$cy_{Pd(-2)}$	-1.08609	1.60034	-1.54271	0.79886
$cy_{Pd(-3)}$	1.06551	3.42706 ***	1.98806 ***	-0.75478
$cy_{Pd(-4)}$	-0.94779	1.88163	-0.47042	-0.39739
$cy_{Pl(-1)}$	0.82396	0.2769	13.896 ***	-0.27372
$cy_{Pl(-2)}$	-1.27115	-0.5653	3.44032 ***	-1.67488 **
$cy_{Pl(-3)}$	1.75208 **	2.45805	1.61623	1.78525 **
$cy_{Pl(-4)}$	-1.27398	-2.08651 ***	0.21774	0.09074
$cy_{Si(-1)}$	1.07214	-0.332	0.28711	8.27731 ***
$cy_{Si(-2)}$	0.20799	-0.33955	-0.6936	3.1394 ***
$cy_{Si(-3)}$	-0.37201	0.82038	1.08308	2.59028 ***
$cy_{Si(-4)}$	-0.54397	-0.74106	-0.19728	1.44957

Panel D — Interval

Interval	cy_{Gd}	cy_{Pd}	cy_{Pl}	cy_{Si}
$cy_{Gd(-1)}$	9.11446 ***	1.11019	-2.32326 ***	-3.66899 ***
$cy_{Gd(-2)}$	4.3899 ***	-1.0063	-1.32197	2.24963 ***
$cy_{Gd(-3)}$	1.60971	1.0465	-0.4828	-1.67522 **
$cy_{Gd(-4)}$	6.64897 ***	2.53574 ***	2.13279 ***	1.61057
$cy_{Pd(-1)}$	0.13084	9.23773 ***	0.51766	-0.28975
$cy_{Pd(-2)}$	0.38759	-1.68071 **	1.35786	0.42728
$cy_{Pd(-3)}$	-0.20734	2.61718 ***	-0.72924	0.18644
$cy_{Pd(-4)}$	0.25501	-2.66951 ***	-0.26753	0.76845
$cy_{Pl(-1)}$	0.88378	-0.93842	17.0094 ***	1.11703
$cy_{Pl(-2)}$	0.6345	1.90954 **	5.94413 ***	-0.53406
$cy_{Pl(-3)}$	-0.30859	-1.67014 **	3.38278 ***	-0.59993
$cy_{Pl(-4)}$	-2.19429 ***	-0.97397	3.55321 ***	-1.64408 **
$cy_{Si(-1)}$	-1.31934	1.10075	-1.08962	11.9341 ***
$cy_{Si(-2)}$	-3.24337 ***	-0.96326	-2.03941 ***	2.0281 ***
$cy_{Si(-3)}$	0.45276	0.70264	0.41092	2.36069 ***
$cy_{Si(-4)}$	-1.9561 **	-0.18031	-2.48054 ***	3.92646 ***

Panel E — GFC

GFC	cy_{Gd}	cy_{Pd}	cy_{Pl}	cy_{Si}
$cy_{Gd(-1)}$	2.8391 ***	2.91549 ***	1.81516 **	1.59256
$cy_{Gd(-2)}$	-0.1676	-0.75866	-0.26599	-0.80062
$cy_{Gd(-3)}$	-0.7401	-1.01306	-1.90229 **	-1.9305 **
$cy_{Gd(-4)}$	1.6434 **	1.04126	1.75931 **	1.2129
$cy_{Pd(-1)}$	-0.9544	-0.14945	-0.99929	-1.70645 **
$cy_{Pd(-2)}$	0.4589	0.80444	0.60907	0.0776
$cy_{Pd(-3)}$	-2.5407 ***	-0.72541	-2.39335 ***	-1.69845 **
$cy_{Pd(-4)}$	-0.3227	1.26752	-0.18219	-0.22976
$cy_{Pl(-1)}$	1.4101	-0.34141	2.18151 ***	1.63861
$cy_{Pl(-2)}$	2.2393 ***	1.22379	1.72144 **	1.72029 **
$cy_{Pl(-3)}$	0.9041	0.30492	1.59127	1.58768
$cy_{Pl(-4)}$	-0.957	-1.03694	-0.87749	-1.19126
$cy_{Si(-1)}$	-0.8442	-0.75775	-0.82699	0.51299
$cy_{Si(-2)}$	-2.311 ***	-1.40543	-1.46059	-0.4618
$cy_{Si(-3)}$	1.8181 **	2.15668 ***	2.37292 ***	3.11113 ***
$cy_{Si(-4)}$	0.5707	0.31616	0.56442	0.72508

Asterisks Indicate corresponding confidence intervals *** P = 0.05, ** P = 0.1

Figure 2C. Sub sample of crisis and non-crisis time periods.

The Nikkei 225 Index, Ftse 100 and S&P500 Indices rebased to 0 at start of our data series. Graphic overlay demonstrates the sub sample estimation windows compared to that of the full sample. (Source: CapitalIq)

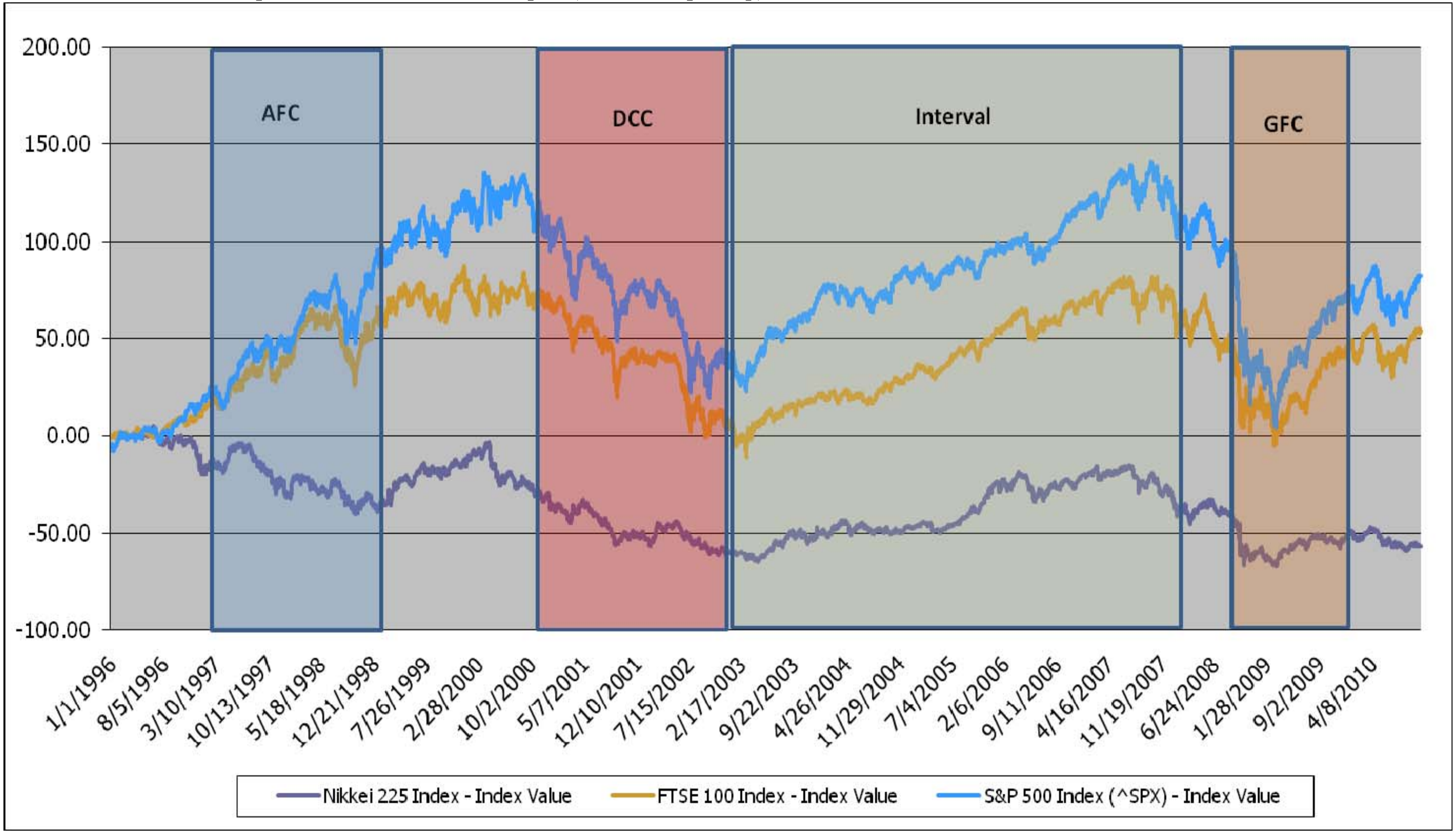


Table 6 VAR routine estimation for the cy against r_i v_i and σ_i.

Results show t-test estimations (asterisks indicate significance as per bottom of table) for full sample, ACC, DCC, Interval and GFC.

Panel A	Full Sample				Panel B	AFC				Panel C	DCC				Panel D	Interval				Panel E	GFC			
Full Sample	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**AFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**DCC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**Interval**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**GFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$
$cy_{Gd(-1)}$	6.81013***	1.8951**	0.97001	3.42241***	$cy_{Gd(-1)}$	7.56531***	-0.5671	-0.3862	-0.2483	$cy_{Gd(-1)}$	0.31546	-0.0948	0.44349	1.96291***	$cy_{Gd(-1)}$	4.76704***	0.88006	-0.2306	-1.4738	$cy_{Gd(-1)}$	0.82773	3.55534***	1.80472**	1.17812
$cy_{Gd(-2)}$	-2.4974***	-2.3654***	-1.6632**	0.82707	$cy_{Gd(-2)}$	-1.3852	-0.5946	1.85856**	2.59514***	$cy_{Gd(-2)}$	-0.2824	1.9454**	1.6575**	0.41467	$cy_{Gd(-2)}$	1.22361	-1.466	-1.2834	-2.0684***	$cy_{Gd(-2)}$	-0.205	-0.4988	-1.8894**	0.6303
$cy_{Gd(-3)}$	-1.0449	-3.0522***	-0.2694	0.0551	$cy_{Gd(-3)}$	-2.6747***	0.93657	-0.8981	-2.0146***	$cy_{Gd(-3)}$	0.77973	-2.4924***	-1.2369	-1.0108	$cy_{Gd(-3)}$	-1.5008	-2.0465***	-0.8977	-2.0163***	$cy_{Gd(-3)}$	-0.6062	-0.4683	1.11259	1.19895
$cy_{Gd(-4)}$	-2.8591***	4.09013***	-0.5436	-4.7431***	$cy_{Gd(-4)}$	-1.7597	0.14136	-1.6991**	-0.4983	$cy_{Gd(-4)}$	-1.0546	0.85212	-0.6973	-0.9245	$cy_{Gd(-4)}$	-1.5671	-0.0239	-0.0212	1.1322	$cy_{Gd(-4)}$	-0.3676	3.72092***	0.41257	-1.5761
Full Sample	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**AFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**DCC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**Interval**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**GFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$
$cy_{Pd(-1)}$	13.0814***	0.16176	1.37024	1.85685**	$cy_{Pd(-1)}$	2.96079***	1.62381	0.5436	-1.5023	$cy_{Pd(-1)}$	11.2272***	-0.7579	-3.3592***	-1.4299	$cy_{Pd(-1)}$	11.7955***	-0.3429	1.01196	4.19505***	$cy_{Pd(-1)}$	1.84594**	0.67773	1.78553**	0.32506
$cy_{Pd(-2)}$	-5.4634***	-0.1625	0.54377	0.10764	$cy_{Pd(-2)}$	-1.5459	-1.6969**	-0.7378	0.63358	$cy_{Pd(-2)}$	-4.3701***	1.13261	3.46428***	1.34663	$cy_{Pd(-2)}$	-2.9567***	0.29967	-0.9946	-0.9381	$cy_{Pd(-2)}$	-1.9365**	-0.9717	0.62499	0.92844
$cy_{Pd(-3)}$	-1.0592	1.40951	0.41166	0.25877	$cy_{Pd(-3)}$	0.08856	1.06656	0.82526	0.06388	$cy_{Pd(-3)}$	-1.8043**	0.65642	0.02224	-0.3604	$cy_{Pd(-3)}$	1.0788	0.74694	0.40627	-0.039	$cy_{Pd(-3)}$	0.01608	1.82084**	0.22184	0.92888
$cy_{Pd(-4)}$	-2.5768***	-1.2207	0.52962	-0.7614	$cy_{Pd(-4)}$	-0.2896	-0.4044	-0.5964	1.10488	$cy_{Pd(-4)}$	-1.6301	-1.9875***	-0.9722	-0.6144	$cy_{Pd(-4)}$	-0.429	-0.4763	-0.3661	-0.5389	$cy_{Pd(-4)}$	0.64119	0.85609	-0.9608	0.2447
Full Sample	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**AFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**DCC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**Interval**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**GFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$
$cy_{Pl(-1)}$	8.22495***	-0.7698	3.69532***	-0.7036	$cy_{Pl(-1)}$	3.23137***	0.29998	1.20363	0.39675	$cy_{Pl(-1)}$	4.9699***	-1.5963	0.62598	0.73286	$cy_{Pl(-1)}$	6.18059***	0.46611	4.87192***	1.48039	$cy_{Pl(-1)}$	-0.0777	2.26728***	1.85527**	1.78518**
$cy_{Pl(-2)}$	-4.605***	0.37944	-3.622***	2.49664***	$cy_{Pl(-2)}$	-0.5447	-1.4693	-1.0603	0.01704	$cy_{Pl(-2)}$	-3.4098***	1.4935	-0.6839	0.58238	$cy_{Pl(-2)}$	-1.8467**	0.66124	-3.7123***	-0.9118	$cy_{Pl(-2)}$	-1.7325	-1.1425	0.54947	2.3696
$cy_{Pl(-3)}$	-1.3771	-1.0626	1.07653	-0.8437	$cy_{Pl(-3)}$	-0.2439	1.19244	0.50859	-0.5535	$cy_{Pl(-3)}$	-0.835	-0.7527	0.40336	-1.2289	$cy_{Pl(-3)}$	-1.4888	-0.9446	-0.2039	-0.426	$cy_{Pl(-3)}$	-0.6489	-0.1441	-0.3571	-0.0429
$cy_{Pl(-4)}$	-0.5201	1.63087	-0.9473	-1.6945**	$cy_{Pl(-4)}$	-1.7297**	0.5221	-1.166	0.20395	$cy_{Pl(-4)}$	0.76681	0.78247	-0.6985	0.12519	$cy_{Pl(-4)}$	-1.7799**	0.27996	-0.8383	-0.0843	$cy_{Pl(-4)}$	1.43978	1.20711	-0.0452	-1.1984
Full Sample	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**AFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**DCC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**Interval**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$	**GFC**	r_{Gd}	σ_{Gd}	v_{Gd}	$\sigma_{Gd(G-K)}$
$cy_{Si(-1)}$	13.0083***	-3.6426***	1.91308**	2.56074***	$cy_{Si(-1)}$	5.70645***	-0.101	3.6338***	2.50528***	$cy_{Si(-1)}$	3.057***	0.19795	-1.0314	2.25425***	$cy_{Si(-1)}$	12.1593***	-2.628	1.30549	0.35269	$cy_{Si(-1)}$	1.20432	-0.7912	3.56173***	1.26097
$cy_{Si(-2)}$	-3.4316***	0.71024	0.96015	0.15016	$cy_{Si(-2)}$	-1.1589	0.88985	1.78028**	1.77847	$cy_{Si(-2)}$	-2.2163***	-0.4282	0.22008	-0.5684	$cy_{Si(-2)}$	-2.5422***	1.27423	0.17751	1.86393**	$cy_{Si(-2)}$	0.30164	-0.085	-0.5478	-0.2368
$cy_{Si(-3)}$	-5.7838***	0.17747	-1.7875**	-0.4897	$cy_{Si(-3)}$	-2.9132	-0.007	-0.7088	-2.6269***	$cy_{Si(-3)}$	0.40484	0.35186	-0.5749	1.25493	$cy_{Si(-3)}$	-2.665***	1.35395	-1.4285	0.6522	$cy_{Si(-3)}$	-2.4333***	1.16238	0.40612	0.581
$cy_{Si(-4)}$	-1.811**	1.60198	0.41333	-2.9425***	$cy_{Si(-4)}$	-0.2791	-1.3413	-3.0319***	-0.8846	$cy_{Si(-4)}$	-0.8084	0.14026	1.86625**	-2.4272***	$cy_{Si(-4)}$	-1.4368	-1.7742**	1.61262	-1.374	$cy_{Si(-4)}$	1.20385	3.23803***	0.27419	-0.5357

Asterisks Indicate corresponding confidence intervals *** P = 0.05, ** P = 0.1

Table 7 VAR routine estimation for the cy_i against cross market variables.

Results show t-test estimations (asterisks indicate significance as per bottom of table) for full sample, ACC, DCC, Interval and GFC

Panel A	Full Sample			
Full Sample	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Gd(-1)}$	2.99888 ***	0.50136	-0.70289	-1.22925
$cy_{Gd(-2)}$	-2.57735 ***	-2.71968 ***	-1.16564	-1.96414 ***
$cy_{Gd(-3)}$	-4.14098 ***	1.01802	-2.04316 ***	-1.77437 **
$cy_{Gd(-4)}$	3.65403 ***	0.5712	3.61164 ***	3.24442 ***
Full Sample	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pl(-1)}$	2.73756 ***	0.95836	0.09471	-0.65217
$cy_{Pl(-2)}$	-1.84417 **	-2.20812 ***	-0.82994	-1.7449 **
$cy_{Pl(-3)}$	-3.37063 ***	1.21414	-1.39391	-2.2365 ***
$cy_{Pl(-4)}$	2.69181 ***	0.24004	2.51249 ***	2.88027 ***
Full Sample	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Si(-1)}$	-0.01237	-2.79521 ***	-3.84237 ***	-4.07698 ***
$cy_{Si(-2)}$	0.08898	-0.60722	-0.31984	0.45284
$cy_{Si(-3)}$	-3.88918 ***	0.62205	-1.08951	-0.55437
$cy_{Si(-4)}$	4.10232 ***	2.39324 ***	4.67016 ***	3.16642 ***
Full Sample	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pd(-1)}$	0.00278	-0.22062	0.4207	-1.46271
$cy_{Pd(-2)}$	-0.21623	-0.78248	-1.05604	-0.32438
$cy_{Pd(-3)}$	-0.70921	1.83012 **	0.02534	-0.51524
$cy_{Pd(-4)}$	-0.06301	-0.13394	-0.28813	0.15487

Panel B	AFC			
AFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Gd(-1)}$	-0.7983	-0.52768	-1.15902	0.12276
$cy_{Gd(-2)}$	-1.40822	0.16237	-0.25925	0.10023
$cy_{Gd(-3)}$	0.55689	0.79616	0.65735	0.31494
$cy_{Gd(-4)}$	0.69806	-0.28343	0.67417	-0.68768
AFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pl(-1)}$	0.60661	0.02967	0.49489	-0.14642
$cy_{Pl(-2)}$	-1.67751 **	-0.48887	-1.69126 **	-0.8634
$cy_{Pl(-3)}$	0.3437	0.60282	0.92789	0.3481
$cy_{Pl(-4)}$	0.58893	0.34375	0.85239	0.86903
AFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Si(-1)}$	-1.65261	-3.1164	-1.24849	-0.54672
$cy_{Si(-2)}$	0.46994	0.77727	-0.53291	0.88395
$cy_{Si(-3)}$	-1.29685	-0.44427	-0.43252	0.50936
$cy_{Si(-4)}$	2.30037 ***	1.7317 **	1.27707	-0.43485
AFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pd(-1)}$	0.04823	0.00825	0.13864	-1.31816
$cy_{Pd(-2)}$	-1.18149	-0.23698	-0.09616	0.26851
$cy_{Pd(-3)}$	0.58043	0.34454	-0.13312	0.75825
$cy_{Pd(-4)}$	0.27158	0.6653	-0.03469	-0.42302

Panel C	DCC			
DCC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Gd(-1)}$	-0.02271	-0.60651	-1.73718 **	-0.84845
$cy_{Gd(-2)}$	1.59488	0.03154	1.43359	1.68769 **
$cy_{Gd(-3)}$	-1.8994 **	0.66594	-0.77801	-0.73794
$cy_{Gd(-4)}$	0.52539	-0.66089	0.92559	-0.44849
DCC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pl(-1)}$	2.47449 ***	0.74368	-1.42292	1.30218
$cy_{Pl(-2)}$	0.46943	-1.24723 *	0.60013	-0.4734
$cy_{Pl(-3)}$	-2.52405 ***	0.34971	0.17772	-1.22195
$cy_{Pl(-4)}$	0.35066	0.08485	0.64535	0.29505
DCC	DCC	DCC	DCC	DCC
$cy_{Si(-1)}$	0.45576	0.69956	-1.845	0.0252
$cy_{Si(-2)}$	0.30235	-0.52958	1.20496	-0.12564
$cy_{Si(-3)}$	-0.8651	0.22272	-0.22994	0.23333
$cy_{Si(-4)}$	0.64418	-0.55172	0.77844	0.30045
DCC	DCC	DCC	DCC	DCC
$cy_{Pd(-1)}$	0.47277	-0.71989	-1.2516	0.55506
$cy_{Pd(-2)}$	1.70288 **	-0.66494	1.26645	-0.00446
$cy_{Pd(-3)}$	-0.96815	1.58003	-1.11148	-0.43758
$cy_{Pd(-4)}$	-1.35645	-0.77842	1.11441	-0.9386

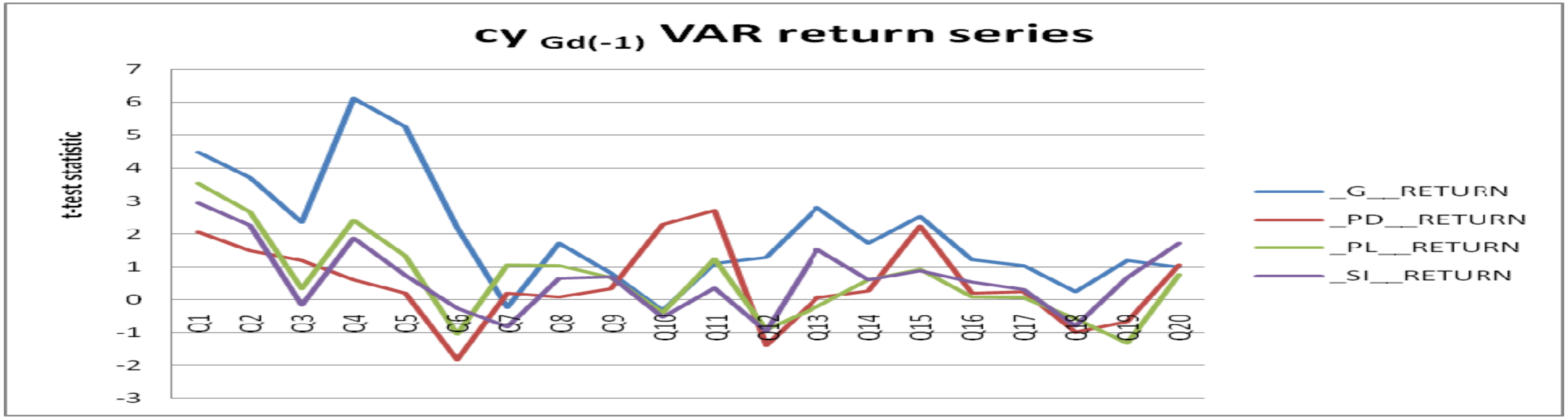
Panel D	Interval			
Interval	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Gd(-1)}$	1.77469	-1.41137	0.23503	-0.65986
$cy_{Gd(-2)}$	-2.67763 ***	-3.47821 ***	-1.95816 **	-1.77954 **
$cy_{Gd(-3)}$	-2.30898 ***	0.85742	-0.44188	-0.31583
$cy_{Gd(-4)}$	-1.08214	-1.45133	0.99022	0.40432
Interval	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pl(-1)}$	0.40874	-0.95225	1.32747	-1.99593 ***
$cy_{Pl(-2)}$	-0.51568	-0.44782	-0.62475	0.12952
$cy_{Pl(-3)}$	-1.43712	1.61562	-0.78347	-1.15016
$cy_{Pl(-4)}$	0.22752	-0.2246	0.93407	1.0038
Interval	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Si(-1)}$	0.57573	-2.79305 ***	-2.30122 ***	-2.42338 ***
$cy_{Si(-2)}$	-0.96582	-1.2633	-2.02378 ***	0.82916
$cy_{Si(-3)}$	-0.24582	1.36997	-0.00159	1.95105 **
$cy_{Si(-4)}$	-0.07793	0.87756	1.51527	-0.01959
Interval	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pd(-1)}$	-0.52399	-1.18435	0.40193	-0.68143
$cy_{Pd(-2)}$	0.33559	-0.615	-1.1963	0.53177
$cy_{Pd(-3)}$	-0.58964	0.80615	0.31064	0.08675
$cy_{Pd(-4)}$	0.05915	-0.27462	-1.06344	0.59078

Panel E	GFC			
GFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Gd(-1)}$	3.61786 ***	1.441	1.47826	0.36704
$cy_{Gd(-2)}$	0.55386	-0.84917	-0.17932	-0.25458
$cy_{Gd(-3)}$	-2.05389 ***	1.52763	0.62451	-0.30265
$cy_{Gd(-4)}$	4.33955 ***	1.48206	1.95615 **	2.77592 ***
GFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pl(-1)}$	3.58044 ***	1.74336 **	2.62544 ***	1.3666
$cy_{Pl(-2)}$	0.31538	-1.04702	-0.15475	-1.21815
$cy_{Pl(-3)}$	-2.04052 ***	1.70848 **	-0.35972	-0.59034
$cy_{Pl(-4)}$	3.95887 ***	0.8438	1.38795	2.37473 ***
GFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Si(-1)}$	2.15429 ***	0.41851	0.04061	-0.81088
$cy_{Si(-2)}$	2.27433 ***	0.08934	1.38629	0.32661
$cy_{Si(-3)}$	-2.23268 ***	0.92631	0.64744	-0.4184
$cy_{Si(-4)}$	4.05332 ***	2.16562 ***	2.68289 ***	3.06045 ***
GFC	σ_{Gd}	σ_{Pd}	σ_{Pl}	σ_{Si}
$cy_{Pd(-1)}$	2.68781 ***	2.0557 ***	1.77381 **	0.12274
$cy_{Pd(-2)}$	0.47886	-1.186	-0.98267	-0.73572
$cy_{Pd(-3)}$	-1.37727	1.39495	-0.13624	-0.70108
$cy_{Pd(-4)}$	3.47521 ***	1.05096	0.98789	2.92151 ***

Asterisks Indicate corresponding confidence intervals *** P = 0.05, ** P = 0.1

Figure 7: 20-Quantile VAR estimation routines for influential cy lags.

We employ a 20 quantile VAR estimation to track the t test statistic over time for both of the influential lags as defined by our earlier estimations routines. Each point dated entry corresponds to separate 173 day VAR of convenience yield against return. Quantiles (Q) 3-5 represent the AFC, Q6-8 represents the DCC, and Q18-20 represents the GFC.



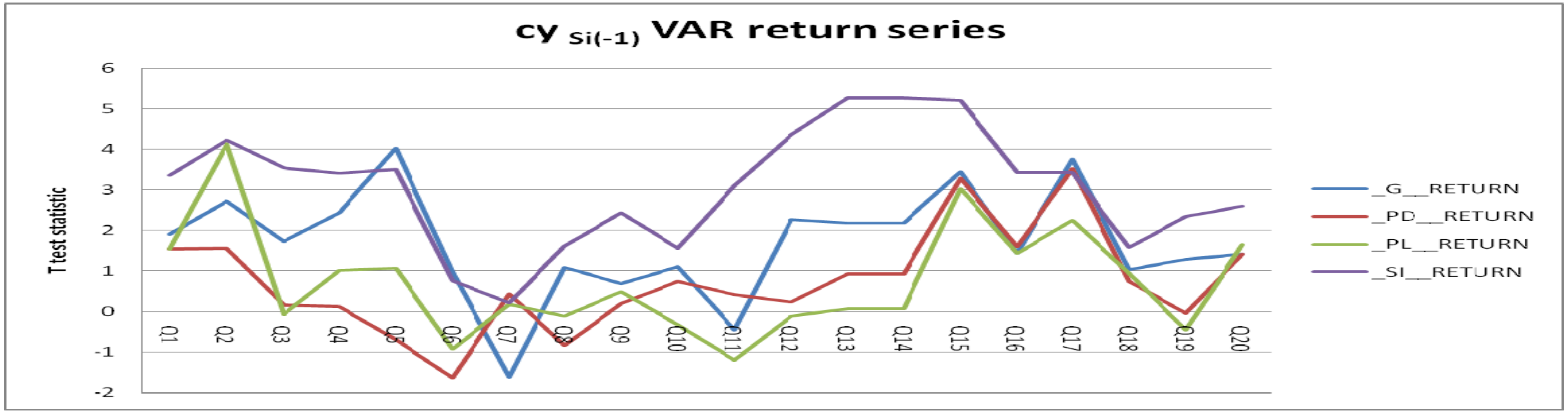
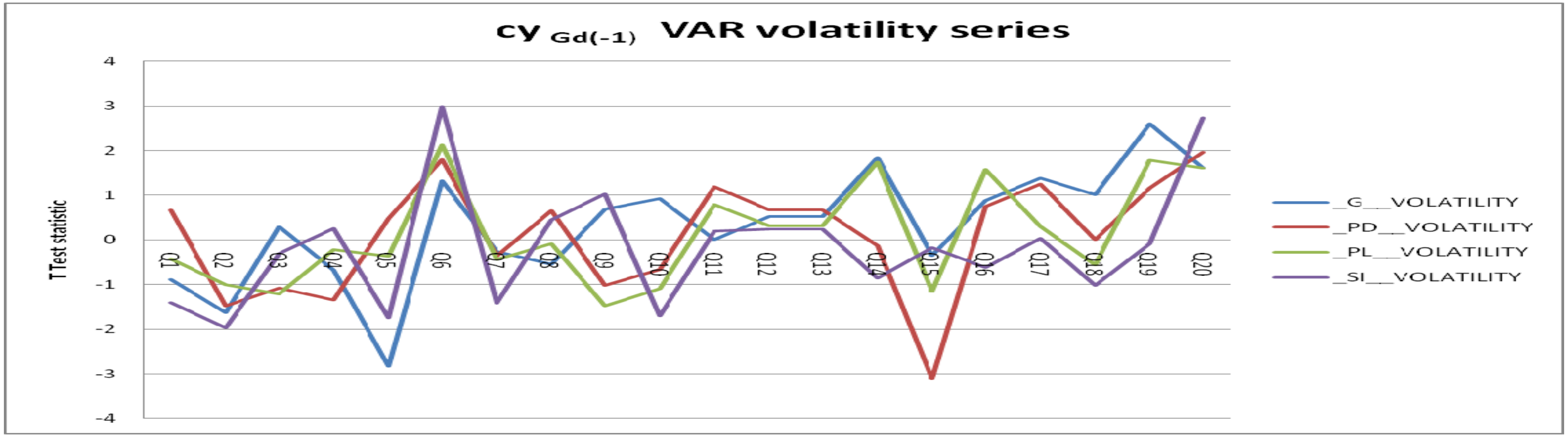


Figure 8: 20-Quantile VAR estimation routines for influential cy_{Gd} lags for the volatility series of all precious metals.

We employ a 20 quantile VAR estimation to track the t test statistic over time for both of the influential lags as defined by our earlier estimations routines. Each point dated entry corresponds to separate 173 day VAR of convenience yield against return. Quantiles (Q) 3-5 represent the AFC, Q6-8 represents the DCC, and Q18-20 represents the GFC.



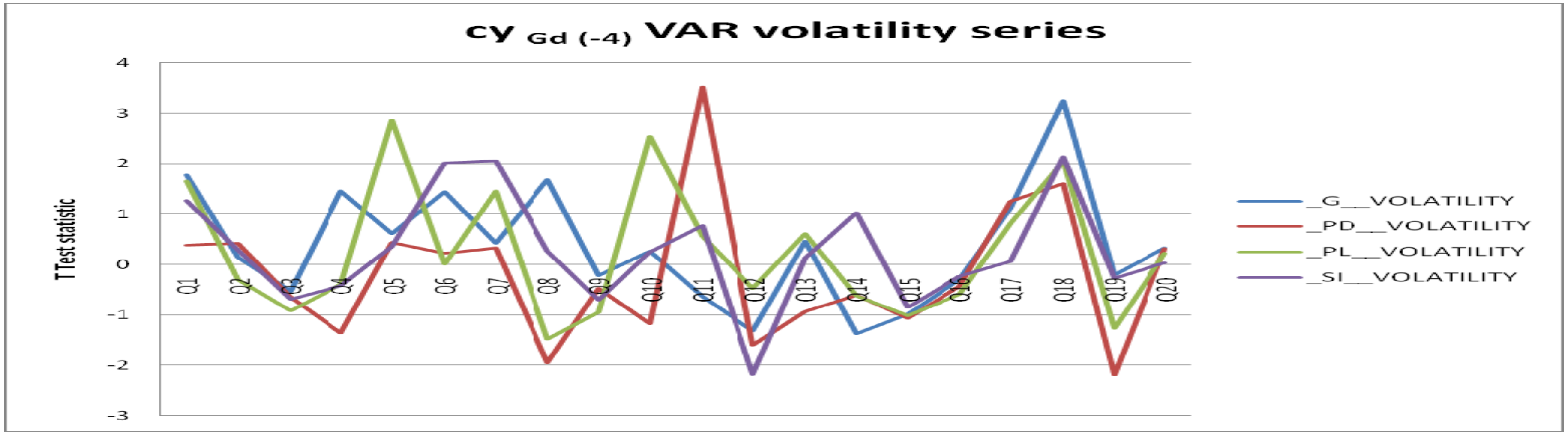


Figure 3: Future / Spot prices (GBP) of the precious metals Gd, Pl, Si and Pd.

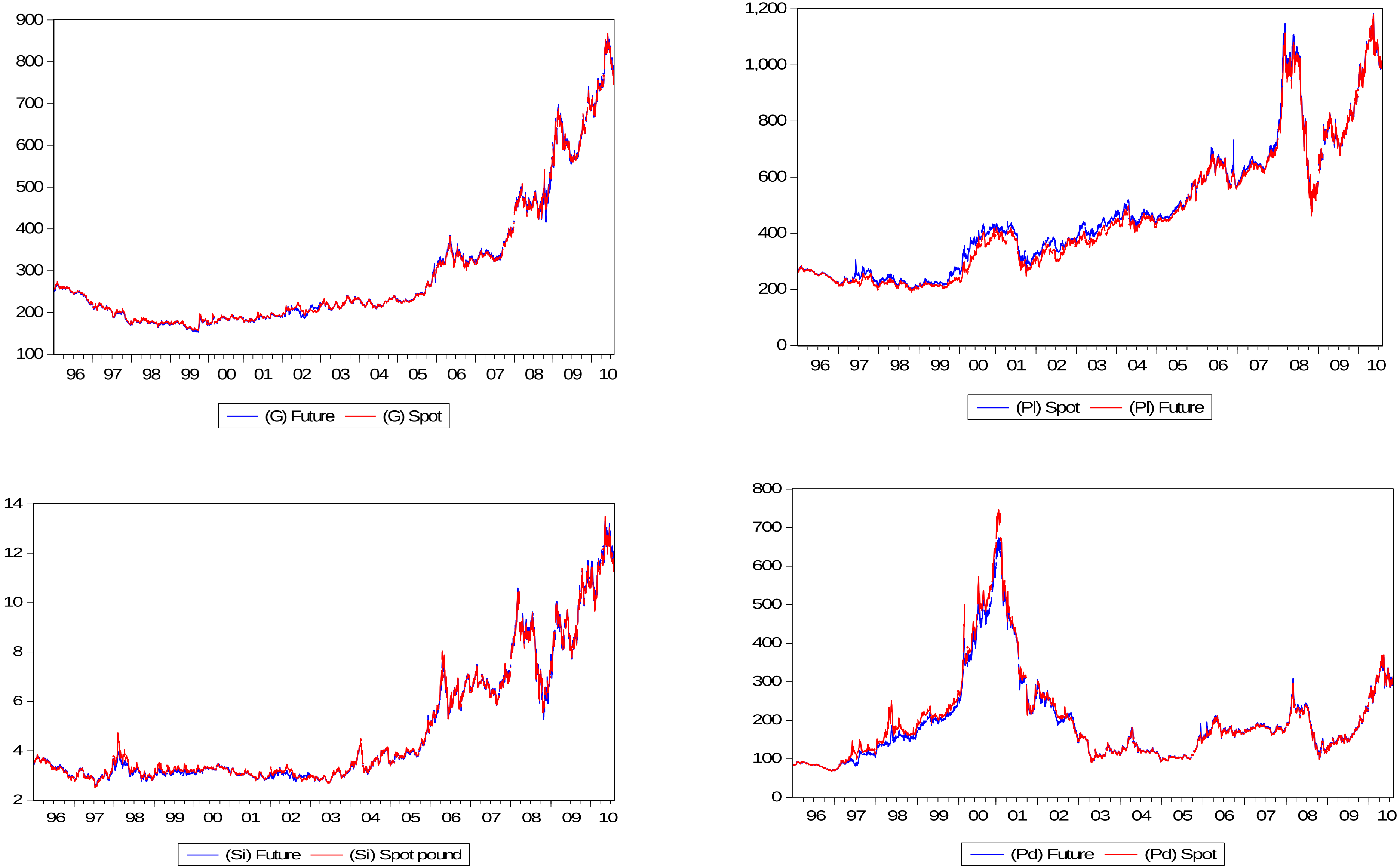


Figure 4. Cy data series for the precious metals Gd, Pl, Si and Pd for the full sample.

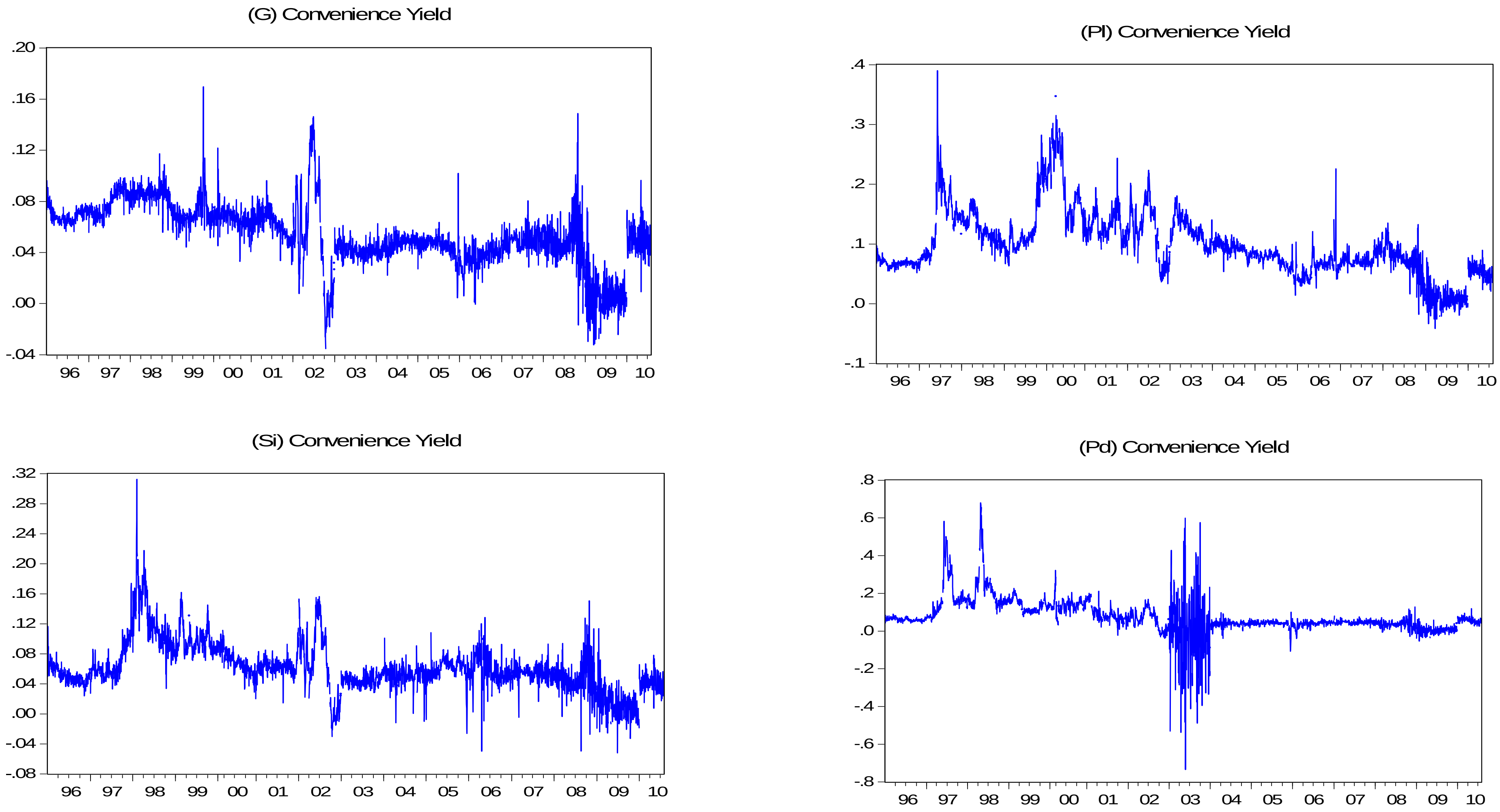


Table 3: Summary statistics of key variables. Panel A represents the statistics of the full sample of data and panel B the notable sub sample period of GFC for comparison. The subsample periods corresponding to the AFC and GFC are excluded for brevity and key statistics are shown in Figure 7

	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	Probability	Sum	Sum Sq. Dev.	Observations
PANEL A - FULL SAMPLE												
cy_{Gd}	0.054425	0.053361	0.169668	-0.035328	0.024576	-0.25654	4.124394	219.6439	0	187.8201	2.083767	3451
r_{Gd}	0.000275	0.00068	0.068677	-0.137146	0.012334	-0.66995	10.50271	8352.276	0	0.947624	0.524821	3451
σ_{Gd}	0.008706	0.006292	0.137146	0	0.00874	2.933	22.8034	61339.33	0	30.04392	0.263523	3451
$\sigma_{Gd(GK)}$	9.80E-05	3.21E-05	0.008014	0	0.000263	12.88996	292.9224	12181972	0	0.338299	0.000238	3451
v_{Gd}	6.82E+10	4.08E+10	5.97E+11	2.67E+09	7.08E+10	2.16E+00	9.60E+00	8954.197	0	2.35E+14	1.73E+25	3451
Spot P_{GD}	294.7067	225.119	860.0883	152.9455	158.3533	1.70331	5.034691	2264.011	0	1017033	86511369	3451
Future P_{GD}	294.5178	225.023	867.45	157.033	157.1293	1.72112	5.088929	2331.245	0	1016381	85179138	3451
cy_{Pd}	0.076549	0.055359	0.680567	-0.735028	0.095513	0.6964	13.34132	15656.43	0	264.17	31.47357	3451
r_{Pd}	0.000332	0.000682	0.164976	-0.218078	0.024113	-0.38645	7.83204	3443.235	0	1.144606	2.005879	3451
σ_{Pd}	0.016909	0.011405	0.218078	0	0.017191	2.3778	14.13582	21083.05	0	58.35194	1.019603	3451
$\sigma_{Pd(GK)}$	0.000183	7.68E-05	0.006803	0	0.000342	7.038574	93.18716	1198056	0	0.63117	0.000403	3451
v_{Pd}	1.57E+09	2.49E+08	3.88E+10	932000	3.62E+09	4.30229	27.14612	94481.77	0	5.43E+12	4.52E+22	3451
Spot P_{Pd}	198.838	169.65	747	67.9	117.0884	2.00477	7.430581	5134.294	0	686189.8	47298472	3451
Future P_{Pd}	460.6409	398.5863	1178.64	189.4339	235.0109	1.002	3.235179	585.4166	0	1589672	1.91E+08	3451
cy_{Pl}	0.09874	0.089161	0.390129	-0.041817	0.054028	0.87866	4.592445	808.6902	0	340.7507	10.07073	3451
r_{Pl}	0.000347	0.00073	0.108936	-0.114585	0.016527	-0.46837	7.677322	3271.956	0	1.196711	0.942295	3451
σ_{Pl}	0.011507	0.007893	0.114585	0	0.011866	2.45579	12.69263	16977.59	0	39.70906	0.485796	3451
$\sigma_{Pl(GK)}$	0.00013	5.68E-05	0.005295	0	0.000299	8.599248	102.3524	1461884	0	0.448898	0.000309	3451
v_{Pl}	3.42E+10	2.55E+10	2.58E+11	1.17E+09	2.90E+10	1.76323	7.561839	4780.534	0	1.18E+14	2.89E+24	3451
Spot P_{Pl}	474.9457	425.8	1183	197.5	231.7285	0.99035	3.304325	577.4351	0	1639038	1.85E+08	3451
Future P_{Pl}	4.78813	3.381294	13.28305	2.563411	2.538491	1.40241	3.904753	1248.914	0	16523.84	22231.59	3451
cy_{Si}	0.061283	0.056526	0.312583	-0.052123	0.033221	0.94974	6.334078	2117.203	0	211.4887	3.807577	3451
r_{Si}	0.00031	0.000605	0.132512	-0.125715	0.018243	-0.26004	8.485039	4364.958	0	1.069855	1.14815	3451
σ_{Si}	0.012951	0.00934	0.132512	0	0.01285	2.65982	16.55076	30472.56	0	44.69389	0.569651	3451
$\sigma_{Si(GK)}$	8.27E-05	2.76E-05	0.003293	0	0.00019	7.42874	84.92566	996844.1	0	0.285389	0.000125	3451
v_{Si}	1.49E+09	1.00E+09	2.78E+10	12952500	1.71E+09	4.62869	44.52682	260288.2	0	5.14E+12	1.01E+22	3451
Spot P_{Si}	4.808999	3.42979	13.489	2.509	2.506434	1.38338	3.844971	1203.381	0	16595.86	21673.62	3451
Future P_{Si}	4.78813	3.381294	13.28305	2.563411	2.538491	1.40241	3.904753	1248.914	0	16523.84	22231.59	3451
PANEL B - GLOBAL FINANCIAL CRISIS												
cy_{Gd}	0.016308	0.010943	0.148723	-0.032329	0.027446	1.617422	6.507291	290.2576	0	4.990342	0.229757	306
r_{Gd}	0.000718	0.002066	0.068677	-0.068677	0.019704	-0.249106	5.099853	59.38438	0	0.219849	0.118416	306
σ_{Gd}	0.014283	0.010459	0.068677	0	0.013568	1.869548	6.76612	359.0972	0	4.37072	0.056145	306
$\sigma_{Gd(GK)}$	0.000335	0.000172	0.008014	0	0.00062	7.560166	83.7041	85957.65	0	0.102504	0.000117	306
v_{Gd}	9.91E+10	9.78E+10	3.69E+11	5.06E+09	7.16E+10	1.041064	4.719819	92.98613	0	3.03E+13	1.57E+24	306
Spot P_{GD}	594.1751	598.1065	731.594	435.663	66.22917	-0.355695	2.580959	8.69129	0.012963	181817.6	1337822	306
Future P_{GD}	594.9323	601.9498	741.1868	415.6339	69.12916	-0.426543	2.654642	10.79962	0.004517	182049.3	1457546	306
cy_{Pd}	0.011661	0.006826	0.128079	-0.053762	0.025946	1.317766	6.095523	210.7357	0	3.568369	0.205321	306
r_{Pd}	0.001027	0.002568	0.125769	-0.125163	0.032634	-0.283918	4.703871	41.12658	0	0.314381	0.324818	306
σ_{Pd}	0.024316	0.018692	0.125769	0	0.021744	1.764538	6.704951	333.8082	0	7.440764	0.144209	306
$\sigma_{Pd(GK)}$	0.000413	0.000267	0.002915	1.24E-05	0.000463	2.414365	10.07672	935.8074	0	0.126492	6.54E-05	306
v_{Pd}	1.08E+08	91721000	4.35E+08	5784000	77938249	1.110702	4.111729	78.67489	0	3.31E+10	1.85E+18	306
Spot P_{Pd}	157.1768	150	246.05	98.75	32.67162	0.786947	2.880376	31.76604	0	48096.1	325567.6	306
Future P_{Pd}	157.8888	151.6604	246.8114	103.1222	32.49112	0.749072	2.86569	28.84658	0.000001	48313.96	321980.3	306
cy_{Pl}	0.017703	0.012132	0.132655	-0.041817	0.026831	1.406087	5.421469	175.5908	0	5.417056	0.219571	306
r_{Pl}	0.000272	0.002826	0.108936	-0.114585	0.029235	-0.41711	5.298038	76.20553	0	0.083133	0.26068	306
σ_{Pl}	0.020984	0.01516	0.114585	0.000286	0.020323	1.904979	7.18215	408.0786	0	6.420954	0.125969	306
$\sigma_{Pl(GK)}$	0.000483	0.000214	0.005295	2.86E-05	0.000767	3.471554	16.4887	2934.436	0	0.147664	0.000179	306
v_{Pl}	1.95E+10	1.85E+10	7.27E+10	1.17E+09	1.33E+10	0.605533	3.326187	20.05675	0.000044	5.97E+12	5.37E+22	306
Spot P_{Pl}	721.6342	743.775	921.35	488.7	104.9216	-0.457994	2.358087	15.95134	0.000344	220820.1	3357605	306
Future P_{Pl}	721.6674	745.3586	928.9553	461.3339	107.2864	-0.499568	2.401215	17.29939	0.000175	220830.2	3510665	306
cy_{Si}	0.020924	0.015515	0.150555	-0.052123	0.029887	1.465951	6.026451	226.382	0	6.402629	0.272433	306
r_{Si}	0.001009	0.002063	0.132512	-0.125715	0.032847	-0.000187	6.12691	124.664	0	0.308814	0.329077	306
σ_{Si}	0.023585	0.01813	0.132512	0	0.022844	2.225288	9.447932	782.6391	0	7.217131	0.15917	306
$\sigma_{Si(GK)}$	0.000344	0.000221	0.003148	2.96E-06	0.000409	2.901124	14.01206	1975.376	0	0.105376	5.11E-05	306
v_{Si}	4.78E+08	3.76E+08	1.92E+09	12952500	3.89E+08	1.195189	4.086458	87.90227	0	1.46E+11	4.62E+19	306
Spot P_{Si}	8.697723	8.739565	11.496	5.52921	1.50115	-0.200742	2.179802	10.6324	0.004911	2661.503	687.3026	306
Future P_{Si}	8.677395	8.690175	11.72142	5.249594	1.54307	-0.189873	2.205389	9.889069	0.007122	2655.283	726.2249	306

Table 4: Correlation Matrix.
Correlation coefficients of key variables with corresponding t – test statistics reported on the second line. Shading represents confidence interval of p =0.05.

Correlation *t-Statistic*	cy_{Gd}	r_{Gd}	σ_{Gd}	ν_{Gd}	cy_{Pd}	r_{Pd}	σ_{Pd}	ν_{Pd}	cy_{Pl}	r_{Pl}	σ_{Pl}	ν_{Pl}	cy_{Si}	r_{Si}	σ_{Si}	ν_{Si}
cy_{Gd}	1															
	-----															
r_{Gd}	-0.198487	1														
	-7.388379	-----														
σ_{Gd}	-0.052631	-0.07521	1													
	-1.922795	*-2.7516*	-----													
ν_{Gd}	-0.089155	0.00078	0.371549	1												
	-3.265647	*0.02847*	*14.60037*	-----												
cy_{Pd}	0.181838	-0.03187	0.040371	0.020404	1											
	6.746462	*-1.16323*	*1.474053*	*0.744561*	-----											
r_{Pd}	-0.129955	0.56866	-0.066016	0.043665	0.049825	1										
	-4.781689	*25.2213*	*-2.413726*	*1.594549*	*1.82*	-----										
σ_{Pd}	-0.117013	-0.09961	0.403614	0.144468	-0.00172	-0.0257	1									
	-4.298509	*-3.65214*	*16.09413*	*5.326496*	*-0.06265*	*-0.93784*	-----									
ν_{Pd}	-0.010171	0.000578	0.124286	0.322776	-0.02002	0.072575	0.209278	1								
	-0.37108	*0.02108*	*4.569737*	*12.44174*	*-0.73061*	*2.65476*	*7.80797*	-----								
cy_{Pl}	0.233005	-0.08936	-0.043301	-0.093749	-0.0518	-0.05899	0.044825	-0.03017	1							
	8.741289	*-3.27314*	*-1.581242*	*-3.435367*	*-1.89244*	*-2.15578*	*1.63698*	*-1.10117*	-----							
r_{Pl}	-0.117841	0.633053	-0.073102	-0.01769	-0.02494	0.589686	-0.11126	-0.01181	-0.02972	1						
	-4.32933	*29.8351*	*-2.674114*	*-0.64548*	*-0.91016*	*26.6377*	*-4.08436*	*-0.4309*	*-1.08483*	-----						
σ_{Pl}	0.023063	-0.10534	0.45926	0.201121	0.04898	-0.08193	0.466206	0.241736	0.107755	-0.08997	1					
	0.841629	*-3.86458*	*18.86194*	*7.490547*	*1.78907*	*-2.99922*	*19.2257*	*9.08877*	*3.95423*	*-3.2958*	-----					
ν_{Pl}	-0.053925	0.013852	0.174449	0.689458	0.051218	0.064545	0.107686	0.397677	-0.07694	-0.00652	0.282754	1				
	-1.970197	*0.50539*	*6.463506*	*34.72663*	*1.87102*	*2.35972*	*3.95169*	*15.8125*	*-2.81536*	*-0.23799*	*10.7546*	-----				
cy_{Si}	0.273651	0.08571	-0.072716	0.046456	0.123666	0.095314	-0.08643	-0.03668	-0.20733	0.058111	-0.10032	0.02424	1			
	10.37978	*3.13848*	*-2.659935*	*1.696692*	*4.54661*	*3.49323*	*-3.16522*	*-1.33896*	*-7.73214*	*2.12363*	*-3.67835*	*0.88459*	-----			
r_{Si}	-0.10653	0.779444	-0.090937	-0.018911	-0.01924	0.526324	-0.11276	0.005482	-0.07225	0.588179	-0.11207	-0.00111	0.132857	1		
	-3.908748	*45.3913*	*-3.331456*	*-0.690036*	*-0.70211*	*22.5828*	*-4.14012*	*0.20001*	*-2.64273*	*26.5335*	*-4.1147*	*-0.04062*	*4.89037*	-----		
σ_{Si}	-0.045211	-0.08278	0.620078	0.229041	0.03397	-0.08695	0.353717	0.12475	-0.11761	-0.09182	0.425069	0.150811	-0.05655	-0.09344	1	
	-1.651108	*-3.0304*	*28.83502*	*8.584285*	*1.24002*	*-3.18429*	*13.7965*	*4.58708*	*-4.3208*	*-3.36409*	*17.1326*	*5.56567*	*-2.06646*	*-3.42386*	-----	
ν_{Si}	-0.194068	0.090739	0.105679	0.42478	0.004696	0.088653	0.097649	0.201715	-0.17643	0.023481	0.039878	0.399038	0.178822	0.051374	0.165027	1
	-7.217359	*3.32412*	*3.877187*	*17.11838*	*0.17133*	*3.2471*	*3.57964*	*7.5136*	*-6.53917*	*0.85687*	*1.45601*	*15.8769*	*6.63082*	*1.87674*	*6.10436*	-----