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Price Discovery in the Chinese Gold Market

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Abstract

This study conducts price discovery analysis in the Chinese gold market. Our results indicate that Chinese gold market price discovery occurs predominantly in the futures market. The result is robust to numerous different measures of price discovery, namely information share, component share, and information leadership share. Partitioning the daily trades into three trading sessions, we find that the dominance of the futures market occurs consistently in all trading sessions. Furthermore, we investigate sequential price discovery within the spot and futures markets; finding that price discovery of both markets occurs more in the night trading session.

JEL: G10, G14

Keywords: Chinese gold market; Futures; Price discovery; Information share; Component share; Information leadership share; Sequential price discovery.

1. INTRODUCTION

This study investigates the price discovery of gold in China in two informationally linked markets – the spot and the futures markets. According to Reuters (2014, 2017), Shanghai Gold Exchange (SGE) is the second largest gold spot exchange and the Shanghai Futures Exchange (SHFE) is the second largest gold futures exchange worldwide. Furthermore, China is the largest consumer of gold worldwide (Reuters, 2014, 2017). For these reasons, the gold market in China is becoming increasingly important with it being of interest to investors and researchers alike. Noticeably, Chinese gold market is mostly traded domestically. The participants are all local players that include domestic banks; and foreign players that include Chinese registered foreign financial institutions required to obtain approval from the regulatory before participation. Therefore, the gold market in China is considered to be a closed financial market. The restriction on foreign players is consistent with the study conducted by Lucey et al. (2014) who find that the gold market in China is isolated with only negligible effects on or from other international markets. This special characteristic makes price discovery of gold within China an even more important topic.

Price discovery refers to the efficient and timely dissemination of information into market prices through trading. If the price discovery process is timely and effective, then the market is said to be efficient (Fama, 1970). In an efficient market, prices reflect new information quickly and adequately (Lehman, 2002). In the case of similar or related products traded at different markets, new information can affect the markets simultaneously. For instance, when gold contracts are traded in spot and futures markets in parallel, price discovery can be defined as which price series is the first to fully reflect new information about the true underlying asset value. In short, price discovery studies attempt to answer the following questions: "Which gold market moves first?" and "Which gold product moves closer to the intrinsic value?"

We use three measures to study the parallel price discovery between the gold spot market and the gold futures market. The first measure is the information share measure derived by Hasbrouck (1995). He uses the variance of the common factors innovation retrieved from a Vector Error Correction Model (VECM) to define price discovery. It measures the price variation contributed by different markets, with the proportion contributed by each market being defined as the information share. The second measure is the component share proposed by Gonzalo and Granger (1995). Component share measures the contribution to the common factor by each market, where contribution is defined as a function of the market error correction coefficients. The market error coefficients are obtained from the VECM, capturing only permanent asset price shocks. Similarly, Lucey et al. (2013) use both information share and component share in their study. The third measure, the information leadership share, is proposed by Putnins (2013) as an adaptation to the measures outlined in Yan and Zivot (2010). He finds that information share responds to both permanent and transitory shocks, while component share captures transitory shocks. He suggests a new measure, information leadership share, by combining information share and component share measures with the new measure capturing only permanent shocks on asset prices. Hauptfleisch et al. (2016) use Putnins (2013) information leadership share to confirm that New York leads the other financial centres in terms of gold price discovery. This finding exhibits the contrasting inferences drawn from using the unmodified Gonzalo and Granger (1995) and Hasbrouck (1995) that led Lucey et al. (2013) to conclude that London was in fact the dominant centre in terms of gold price discovery.

In addition to conducting parallel price discovery on gold spot and futures markets, we also carry out sequential price discovery analysis across morning, afternoon, and night sessions within the market. We employ three measures to compare price discovery across trading sessions. The first sequential price discovery measure is the variance ratio between two-scale realized variance and realized variance (TSRV/RV) proposed by Wang and Yang (2011). Intuitively, TSRV is a variance that is induced by pure information while RV captures both variances caused by information and microstructure noise. Therefore, the ratio TSRV/RV provides a measure for the price efficiency of a trading session. The second measure is a modified information share measure also proposed by Wang and Yang (2011). The information share of a particular trading session is its share of the total efficient price variance for the full trading day. The third measure for the sequential price discovery is the weighted price contribution (WPC). WPC is a simple and convenient measure that uses the share of price change in different trading sessions to measure the level of efficient information, see, for example, Cao et al. (2000), and Wang and Yang (2015).

Our results show that price discovery in Chinese gold occurs predominantly in the futures market. Using information share as the measure of price discovery, we find that 31.90% of price variation is attributable to the spot market while 68.10% is attributable to the futures market. Furthermore, the results provided by the component share and information leadership share measures are consistent with those provided by the information share measure. On average, the component share is 37.10% for the spot market and 62.90% for the futures market. The information leadership share is 35.97% for the spot market and 64.03% for the futures market. This result is also consistent across all three trading sessions. The overall result is consistent with prior price discovery studies on spot and derivative markets. Hauptfleisch et al. (2016) find that New York futures play a larger role than the London spot market in setting the price of gold. Chan (1992) and Kawaller et al. (1987) report that S&P 500 index futures price changes lead those on the spot market. One popular explanation for the dominant role played by the futures market is the higher liquidity and lower cost of trading compared to those of the spot market. In our sample, the number of trades and the trading volume in the gold futures market are indeed higher, with the volume more than four times those of the spot market. This also seems to support the argument that different investors focus on different markets. For instance, spot gold is predominantly used by slower moving longer-term investors seeking safe haven assets, whereas the futures market predominantly comprises faster moving speculative investors. We cautiously accept this explanation because higher trading activity does not necessarily explain the price discovery dominance. Hauptfleisch et al. (2016) find that the New York gold futures market plays a larger role in price discovery despite the London spot market account a much higher total gold turnover.

For sequential price discovery, we find that both the spot and futures markets are equally efficient across the three trading sessions (morning, afternoon, and night). However, the overall price contribution occurs more in the night trading session for both markets. The sequential price discovery reveals that there is no economic difference in market efficiency across the three trading sessions, but that most material information enters the Chinese gold market during the night trading session.

To the best of our knowledge, no academic study has analyzed intraday price discovery of gold market in China. The goal of this paper is to fill this gap and allow researchers to understand the price discovery process of the gold market in China. The prior study by Lucey et al. (2014) confirms that the Shanghai gold market is an isolated market in terms of gold price volatility and return spillover, making price discovery of gold within the Chinese market a necessity[1]. Bertus and Stanhouse (2001) point out that gold is associated with low storage costs, low transaction costs, and stable supply. Therefore, the relationship between gold spot and futures ought to be more stable than for other commodities. Using gold in this study is therefore a natural choice because of the lower market friction and this stable relationship. We not only investigate price discovery across markets but also within markets in this study. The cross-market aspect utilizes parallel price discovery methods to investigate whether spot or futures markets respond to information more rapidly. The within market aspect utilizes the sequential price discovery method to study which trading session has higher information intensity, thus contributing to greater price discovery. The conclusion drawn in this study is potentially applicable to other Chinese commodity markets. Our study is also related to other studies of gold price discovery, including the comparison of London gold spot and New York gold futures market (Lucey et al., 2013), US and Japan gold and precious metals futures markets (Lin et al., 2008, Xu and Fung, 2005), and US-Japan-India gold futures markets (Fuangkasem et al., 2014).

For other related literature, Skoyles (2013), Xu et al. (2011), and Cheng (2014a) provide a more detail discussion of the gold market in China. Xu et al. (2011) is one of the first papers that studies the benefits of hedging using gold futures contracts in China. For end users, e.g. jewellers and industrial users, futures contracts provide a mechanism to hedge gold price risk. Furthermore, gold has traditionally been used for portfolio diversification due to its low correlation with stocks and bonds. Hedging demand for gold futures can also come from a wide range of investors, including large pension funds with long-term investments. Gold prices have high correlations with many other commodities and gold trading is more liquid than many other commodities. Therefore, gold is often held as a substitute for less liquid commodities.

[1] The disconnect between Chinese gold and other international markets may lead to inefficiency (i.e. price disparity). This does not mean that an arbitrage opportunity automatically arises, as participation in the gold futures market in China is restricted, and moving physical gold bullion bars across borders can be very costly. However, the presence of arbitragers may actually help to improve gold price efficiency between China and other international markets.

Through this dynamic gold becomes a vehicle for hedging commodity risk in general. A hedger utilising gold could be a Chinese fund manager anticipating stronger economic growth and thus higher commodity prices. The fund manager may therefore take a long position in a spot gold ETF and a short position in gold futures. This further highlights the importance of the study of price discovery in the Chinese gold market.

The rest of the paper is organized as follows. In Section 2 introduces the gold market in China. Section 3 presents the measures of price discovery and detail the econometric methods employed in the paper. Section 4 is devoted to the description and summary statistics of the data used in our study. We present our main findings in Section 5, and Section 6 concludes.

2. Gold Market in China

2.1 Gold Trading

There are three markets in China for gold contract transactions: the spot, futures, and OTC markets. Despite being very new, the Shanghai Gold Exchange (SGE) is the second largest gold spot exchange and the Shanghai Futures Exchange (SHFE) is the second largest gold futures exchange worldwide in 2013 (Reuters, 2014).[2] The Shanghai Gold Exchange (SGE) is one of the world's largest physical gold exchange and nearly all physical gold bars in China flow through the SGE. It was officially established in October 2002 and it was the first to offer a night trading session in the domestic financial market in November 2005 (Wang, 2011). It had 166 members, as of October 2013, including domestic commercial banks, foreign financial institutions, gold producers, smelting institutions, and other major gold consumption and investment firms. The total gold trading volume at the SGE was 10,700 tons[3] in 2013, a sharp increase of 75% from the previous year. Panel A of Figure A1 presents the gold contract price and volume transacted at SGE from 2009 to 2017. It shows sporadic surges in volume, and an upward trend. The physical delivery of gold spot

[2] According to Reuters (2017), SGE is still the second largest gold spot exchange worldwide, while SHFE maintains its second place for gold futures market worldwide, in 2016. The world's largest gold spot market is London OTC, while the world's largest gold futures exchange is COMEX.

[3] The volume is round-trip volume, i.e. one transaction is counted twice. The figures reported in Table A1 is single-trip volume. The volume has increased to 15,492 tons (single-trip) in 2016 (Reuters, 2017).

contracts was 37% of trading volume, with the SGE representing the main channel of physical gold supply. There are eight types of contracts traded on the SGE, but the dominant contract is AU (T+D), which is a delayed gold spot contract. T+D indicates that the physical delivery of gold is delayed by D days after the transaction day. In 2013, the traded volume of AU (T+D) contract was 6,695 tons, representing 63% of the gold spot contracts traded on the SGE. The key features of the AU (T+D) contracts are summarized in Table A2 of the Appendix. In this study, we use AU (T+D) to represent gold spot contracts in China.

To promote international participation and market integration, the SGE opened a wholly owned subsidiary "the Shanghai International Gold Exchange" (SGEI) in the Shanghai Pilot Free Trade Zone (FTZ) in 2014. Members of the SGEI include many large global bullion banks (e.g. HSBC, ANZ, JP Morgan, Scotia, etc.) and the world's best known gold refineries (e.g. MKS, Heraeus, Metalor, etc.). The SGEI has a separate gold bullion vault in the FTZ. Members of the SGE and the SGEI can trade on either exchanges. However, settlements for the SGE trades cannot be made using gold in the SGEI vault, and likewise settlements for the SGE trades cannot be made against gold in the SGE vault.[4] With strict restrictions on moving gold between the vaults, SGE and SGEI are not fully integrated.

Gold futures trading at the Shanghai Futures Exchange (SHFE) was established in January 2008 from the merger of the Shanghai Metal Exchange, Shanghai Cereals and Oil Exchange, and Shanghai Commodity Exchange. It is the largest commodities market in China, and it has futures contracts on precious metals, rubber, steel products, and others. According to the Futures Industry Association annual volume survey (Acworth, 2014), gold futures trading volume in China increased from 3.9 million lots in 2008 to 20 million lots in 2013. On July 5, 2013, the SHFE started night trading sessions for the gold futures contracts. The total trading volume in 2013 is 20,088 tons[5], meaning that the SHFE is the world's second largest gold futures market after COMEX (see Table A1 in the Appendix). Panel B of Figure A1 presents the gold futures price and volume transacted at SHFE from 2009 to 2017. Similar to the volume trend in

[4] An exception is for investors with a license from the central bank to import gold into China.
[5] The trading volume of SHFE is 34,760 tons in 2016, and SHFE remains as the world's second largest gold futures market in 2016.

the SGE in Panel A, the volume at SHFE shows sporadic surges but it is moving upward generally. In contrast to the spot market where it is used mainly as a market for physical gold trading, the futures market serves primarily as a market for risk management. The physical delivery of contracts is only 0.02% of the total trading volume. The key features of gold futures contracts are summarized in Table A2 in the Appendix.

The over-the-counter (OTC) market for gold trading in China was established in May 2002. It is participated in predominantly by commercial banks. The contracts traded include physical gold, account gold, gold loan, and gold derivatives. The total trading volume in the OTC market was 4,500 tons in 2013, with the combined trading volume for all three gold trading platforms in China (SGE, SHFE, and OTC) exceeding 35,000 tons in 2013. China is the second largest gold trading market around the world, ranked just behind the US. While it is unlikely that China will overtake the UK and the US in the near future, gold trading in China is fast growing and garnering greater levels of attention from investors. For these reasons, we believe that the study of price discovery and the gold trading market mechanism in China is of great interest to readers.

2.2 The Growth of Gold Demand[6]

China is the largest gold consumer worldwide, accounting for 34% of global gold demand in 2013 (Reuters, 2014). China has a strong culture affinity with gold, and it symbolizes money and wealth despite the private ownership of gold bullion being prohibited from 1950 to 2004. According to Cheng (2014a, 2014b), the main private demand for gold in China was driven by jewellery, investment, and industrial applications. In 2013, 60% of all private sector gold demand (669 tons) was driven by jewellery. The growth has been supported by rising incomes and the emerging middle class. The demand is from the actual purchase as well as the inventory needs due to the higher number of jewellery stores.

[6] This sub-section is heavily referenced from Cheng (2014a, 2014b), and World Gold Council (2017).

China has become the world's largest market for gold bullion, with the investment needs of gold accounting for 397 tons in 2013. The growth in gold investment reflects the investors' desire for diversification, as well as the limited investment options in China. The gold demand from the industrial application rises steadily and accounts for 66 tons of gold in 2013. Electronics is the dominant source of industrial demand, while decorative (electroplating) is another area of industrial demand. Apart from the private demand, the official gold reserve also forms part of the gold demand. The level of official monetary gold reserve did not change between 2009 and 2013. However, the consumer appetite for gold soared while the estimated per capita gold consumption is only 4.5 grams in China in 2013, compared to 24 grams worldwide. Xu (2014) therefore, argues that there is significant growth potential in gold consumption in China.

The gold supply in China consists of mine production, recycled gold, and imports. The supply comes mainly from over 600 primary mines, with the top 10 producers accounting for about half of the output. While China is the largest gold producing country, the demand exceeds its supply and therefore the difference is fulfilled by imports. Most of the imports are in the form of bullion from Hong Kong, which is geographically close to the largest physical gold hub in Shenzhen.

3. PRICE DISCOVERY METHODOLOGY

3.1 Information Share Measure

We model the dynamic relation between the spot price and futures price series using the VECM. If the spot price and futures price are two cointegrated $I(1)$ price series, the price system can be modeled by the following VECM:

$$\Delta\begin{pmatrix} F_t \\ S_t \end{pmatrix} = \begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix} + \alpha\beta' \begin{pmatrix} F_{t-1} \\ S_{t-1} \end{pmatrix} + \sum_{i=1}^{k} \Gamma_i \begin{pmatrix} \Delta F_{t-i} \\ \Delta S_{t-i} \end{pmatrix} + \begin{pmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{pmatrix}, \tag{1}$$

where ΔS_t and ΔF_t are the log returns of spot and futures markets, α is the error correction vector which measures the speed of adjustment, β is the cointegrating vector (1,-1)′, Γ is the common factor coefficient vector, ε_t is a zero-mean vector of serially uncorrelated innovation with the following correlation matrix:

$$\Omega = \begin{pmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{pmatrix}, \tag{2}$$

where σ_1^2 is the variance of gold futures, σ_2^2 is the variance of gold spot, $\rho\sigma_1\sigma_2$ is the covariance between gold futures and spot.

The VECM has two components. The first component, $\alpha\beta' \begin{pmatrix} F_{t-1} \\ S_{t-1} \end{pmatrix}$, represents the long-run equilibrium between spot and futures prices. The second component, $\sum_{i=1}^{k} \Gamma_i \begin{pmatrix} \Delta F_{t-i} \\ \Delta S_{t-i} \end{pmatrix}$ captures the short-run dynamics induced by market shocks.

Hasbrouck (1995) measures price discovery as a variance that is generated by information shocks on the common factors. It focuses on the relative contribution of the price movement to total price variance in the respective markets. The market with the larger contribution to the total price variation plays a dominant role in the price discovery process. Following the notation of Hasbrouck (1995), the market with higher information share (IS) moves the price upon an information shock. Eq. (1) can be expressed in a vector moving average (VMA) form:

$$\Delta Y_t = \Psi(\mathrm{L})\,\mathrm{e}_t, \tag{3}$$

and its integrated form is:

$$Y_t = \Psi(1)\sum_{s=1}^{t} \mathrm{e}_s + \Psi^*(L)\,\mathrm{e}_t, \tag{4}$$

where Y_t is $(F_t, S_t)'$, $\Psi(L)$ and $\Psi^*(L)$ are matrix polynomials in the lag operator, *L*. Ψ(1) is the impact matrix that is the sum of the moving average coefficients. $\Psi(1)e_t$ is the long-run effect of an information shocks on each of the prices. The weighted variance of each of the market is used to determine the price discovery. Specifically, Hasbrouck (1995) derives the information share (*IS*) of the respective markets as:

$$IS_i = \frac{\Psi_i^2 \sigma_i^2}{\Psi \Omega \Psi'}, \tag{5}$$

where *i* represents the distinct markets (spot market or futures market). Under the condition of no correlation between the innovations of both markets, the covariance matrix **Ω** is diagonal. As a result, the contribution of the innovations on one market to the total variance can be simplified as in Eq. (6).

$$IS_1 = \frac{\gamma_1^2 \sigma_1^2}{\gamma_1^2 \sigma_1^2 + \gamma_2^2 \sigma_2^2} \text{ and } IS_2 = \frac{\gamma_2^2 \sigma_2^2}{\gamma_1^2 \sigma_1^2 + \gamma_2^2 \sigma_2^2}, \tag{6}$$

γ_i measures the contribution by each market to the total innovation, σ_1^2 and σ_2^2 is the variance of gold futures and spot, respectively.

If **Ω** is not diagonal, the upper and lower bounds on the information share can be calculated by Cholesky factorizations of **Ω**, and the IS of the respective markets need to be a simple average taken of the two bounds.

3.2 Component Share Measure

The component share (*CS*) is based on Gonzalo and Grangers' (1995) permanent-transitory decomposition. The approach focuses on the components of the common factor and the error correction process. The *CS* measures the contribution to the common factor by each of the market, where contribution is defined as a function of market error correction coefficients. From the VECM system defined in Eq. (1), the two-dimensional cointegrating vector $Y_t = (F_t, S_t)'$ can be decomposed as:

$$Y_t = Af_t + g_t, \tag{7}$$

where A is a loading matrix, f_t is the common factor, and g_t is the transitory component that does not have a permanent impact on Y_t. Furthermore, Gonzalo and Granger (1995) define common factor f_t as $\alpha'_{\perp}$. In a two-variable system, we assume $\alpha_{\perp} = (\gamma_1, \gamma_2)$ or the contribution of each market to the price discovery is defined as its common factor weights. Based on $\gamma_1\alpha_1 + \gamma_1\alpha_2 = 0$ and $\gamma_1 + \gamma_2 = 1$, the component share of the two markers are:

$$\gamma_1 = \frac{\alpha_2}{\alpha_2 - \alpha_1} \quad \text{and} \quad \gamma_2 = \frac{\alpha_1}{\alpha_1 - \alpha_2}. \tag{8}$$

The *CS* equation does not restrict the factor weight to be positive. However, Cabrera et al. (2009) propose an adjusted *CS* equation to restrict the factor weights to be positive. In the case of two markets, the *CS* of two markets are as follow:

$$CS_1 = \frac{|\gamma_1|}{|\gamma_1| + |\gamma_2|} \quad \text{and} \quad CS_2 = \frac{|\gamma_2|}{|\gamma_1| + |\gamma_2|}. \tag{9}$$

3.3 Information Leadership Share Measure

Yan and Zivot (2010) use a structural model to analyze the responses of *IS* and *CS* to permanent and transitory shocks. They explain that *CS* can only be explained by transitory shocks, while *IS* can be explained by both permanent and transitory shocks. They propose a new measure by combining *IS* and *CS* in such a way that their departure of noise cancels out. Therefore, the combined measure captures only the pure permanent shocks. Putnins (2013) generalizes Yan and Zivot (2010) measure and coin the new measure as information leadership share (ILS) that is more comparable to IS and CS because all the shares are summed to 1. The information leadership share (*ILS*) metric is defined as:

$$ILS_1 = \frac{\frac{IS_1}{IS_2}\frac{CS_2}{CS_1}}{\frac{IS_1}{IS_2}\frac{CS_2}{CS_1} + \frac{IS_2}{IS_1}\frac{CS_1}{CS_2}} \text{ and } \mathrm{ILS}_2 = \frac{\frac{IS_2}{IS_1}\frac{CS_1}{CS_2}}{\frac{IS_1}{IS_2}\frac{CS_2}{CS_1} + \frac{IS_2}{IS_1}\frac{CS_1}{CS_2}}. \tag{10}$$

Yan and Zivot (2010) assume that the price series fluctuates due to two important reasons; noise in the information environment and the speed of adjustment in response to the new information. Putnins (2013) compares *IS*, *CS*, and *ILS* measures by a simulated series. Specifically, he studies the impact of different levels of noise and different speed of adjustment to new information on the three price discovery measures. Putnins (2013) concludes that only *ILS* measures the speed at which a market reflects new information, and is informative about where information is first disseminated into the market. On the other hand, he concludes that *IS* and *CS* measures can accurately measure price discovery only when the two price series have a similar level of noise.

3.4 Sequential Price Discovery Measures

We not only study the parallel price discovery process across the spot and future markets but also carry out analysis of the sequential price discovery process for the spot and futures markets. There are three trading sessions in a trading day for the Chinese gold market: Morning, Afternoon, and Night trading sessions. We examine the session-specific contribution to price discovery in sequential (i.e., non-overlapping) trading sessions. We utilize three sequential price discovery measures in our analysis: (1) variance ratio or TSRV/RV, (2) sequential information share, and (3) weighted price contribution or WPC.

The first measure is the variance ratio of two-scale realized variance and realized variance (TSRV/RV) proposed by Wang and Yang (2011). Two-scale realized variance presented in Eq. (11) is a consistent estimator of the integrated variance proposed by Zhang et al. (2005). It measures the price variance induced purely by the information flow, with the noise component associated with the high-frequency return autocorrelation being removed. On the other hand, the realized variance (RV) measures the price variance attributable not only to information but also microstructure noise. The ratio TSRV/RV provides a measure for the price efficiency of a trading session.

$$TSRV = \frac{1}{k}\sum_{j=1}^{k} RV_{30sec,j} - \frac{m-k+1}{m \times k} RV_{1sec} \tag{11}$$

In Eq. (11), RV_{1sec} is the realized variance based on 1-second returns. $RV_{30sec,j}$ is the 30-second realized variance starting from the beginning of the *j*-th 1-second interval. $k=30$ is the number of sub-observations (1-second) in the sub-grid interval (30-second), and m is total number of 1-second observations in a trading session.

Wang and Yang (2011) also propose an alternate measure to analyze sequential price discovery. Their rationale is based on Hasbrouck's (1995) information share. The information share of a particular trading session is its share of the total variance of the efficient price in a trading day. They use two-scale realized variance (TSRV) to measure information flow and to estimate the information share (IS) across sequential trading sessions. Specifically, in our application, we estimate the TSRV for all three trading sessions within a given trading day, then we compute the information share of a specific session as follows:

$$IS(TSRV)_i = \frac{TSRV_i}{TSRV_1 + TSRV_2 + TSRV_3}, i = 1, 2, 3, \tag{12}$$

where *i* represents one of the three trading sessions within a trading day.

We employ weighted price contribution (WPC) proposed by Barclay and Warner (1993) as the third sequential price discovery measure. The WPC measures how much of the cumulative price change of gold over a given time period is attributable to trades that happened in a specific trading session. It measures the WPC of trading session *i* to daily price change and is widely used in conducting sequential price discovery analysis. For example, Cao et al. (2000) adopt it to examine price discovery during the preopening period for NASDAQ. Wang and Yang (2015) examine the theoretical properties and empirical performance of the WPC in sequential markets. It is determined by:

$$WPC_i = \sum_{t=1}^{T} \left(\frac{r_{i,t}}{r_t} \right) \times \left(\frac{|r_t|}{\sum_{s=1}^{T} |r_s|} \right), \tag{13}$$

where $r_{i,t}$ is the log return during trading session i on day t. r_t is the overall daily return. There are three trading sessions (i.e., *i=1, 2, and 3*) in each trading day in our study. The first term in parentheses is the relative contribution of the return of period i on day t to the overall daily return on day t; the second term in parentheses is the weighting factor for each day.

4. DATA DESCRIPTION

4.1 Data and Sample Selection

The data for spot and futures trading is snapshot tick records that happen two times every second; it includes time, transaction price, volume, and open interest. All transactions are recorded in the data except the call auction periods that are before the market opening and after the market closing. The sample period of the data used in the study is from January 4, 2012 to October 18, 2013, resulting in 429 trading days. The data is obtained from the trading on Shanghai Gold Exchange and Shanghai Futures Exchange.[7]

The trading hours for the gold spot is 9:00-11:30, 13:30-15:30, and 21:00-2:30, Monday to Friday. However, there is no night trading on Friday before May 31, 2013. The trading hours for gold futures is 9:00-11:30, 13:30-15:00, and 21:00-2:30 on Monday to Friday. The night trading of futures starts from July 5, 2013. In order to conduct price discovery analysis on gold prices across the spot and future markets, we employ data from trading times that are common across both markets. That means to say, we use trading hours of futures as the benchmark, but we include night trading on Fridays only from July 5, 2013 onwards. We label the three trading sessions as the morning, afternoon, and night in our empirical analysis.

There are twelve gold futures contracts traded on the market at any one time, with each contract having a different maturity time of between one and twelve months. On the 15th of each month, one contract

[7] The dataset is provided by Wenhua Information Systems Limited, a Chinese financial data provider.

expires and a new contract with a one-year maturity is originated. There are two common methods to construct a single time series of price data from multiple contracts with different maturities. The first commonly used method is to adopt the nearest-to-maturity contract as the representative contract in constructing the price series. This method is outlined in Booth et al. (1999) and is based on the rationale that the expiring contract has more information contained in its price. They splice the price of nearest-to-maturity futures contracts conditional on liquidity. This method was employed in recent empirical research such as Shastri et al. (2008), Chen and Gau (2010), Cabrera et al. (2009), and Covrig et al. (2004). The second commonly used method utilizes only recently issued or on-the-run contracts instead of expiring contracts. Fricke et al. (2011) present the method using on-the-run contracts with the highest trading volume when combining prices of multiple contracts into a single price series. Both methods examine the trading activity or liquidity when combining prices of different contracts.

However, the trading of Chinese gold futures has an obvious peculiarity in that trading is dominated by contracts that mature in June and December. Table 1 shows the trading statistics for the contracts with maturity in June, in December, and sum of those in other months for each trading month. Similar to Xu et al. (2011), we find that the contracts with maturity in June and December contribute about 99% of the trading volume to each and every month[8]. We carry out tests and find that the volume of the dominate contracts (June or December) are statistically larger than those of other months at a 1% significance level. From January to April 2012, the contract with the highest trading volume is the contract that matures in June 2012. However, the relative trading volume of the June 2012 contract declines in April 2012, with the turnover ratio decreasing from 98.2% of total market volume in January to 31.7% in April 2012. As for the December 2012 contract, the volume increases from 1.5% of total market volume in January to 67.9% in April. In summary, the dominant contract is the June 2012 contract from January-March 2012, and it switches to the December 2012 contract for the April-October 2012 period. The dominant contract switches

[8] We believe that the June and December contracts are the most actively traded due primarily to their ease of settlement. As most futures contracts are closed out prior to physical delivery, liquidity is very important to these traders. Therefore, most traders trade only the active contracts, resulting in a self-fulfilling prophecy.

back to the June contract in November 2012. Therefore, we construct the time series of return of futures contract from the contracts with June and December maturity. Specifically, we combine the two series conditional on the trading volume of the contract. This method is similar to Booth et al. (1999) but with a slight modification to discard contracts other than June and December.

[Insert Table 1 Around Here]

4.2 Determine the Sampling Interval

When constructing a continuous time-series of return for spot and futures markets, we need to sample the price from each market at a fixed time interval. We want to sample the price information as frequently as possible to ensure the information is not lost between samplings, but also want to wait for a longer interval for more information to be integrated into the price. We analyze our data with time intervals of 10-second, 30-second, 1-minute, 2-minute, 3-minute, 5-minute, 10-minute, and 15-minute and compute the non-trading probability in these intervals. We need to find an appropriate sampling interval for the spot and futures price series in our study.

Table 2 presents the trading frequency and the non-trading probability within each time interval. Our first observation is that the trading of futures is more active than those of spot. On average, there are about 24 trades per minute in the futures market, and only slightly more than three trades per minute in the spot market. In the 30-second interval, the non-trading probabilities are 29.8% in the spot market and 1.0% in the futures market, respectively. The non-trading probability reduces as we choose a longer interval. Among the three trading sessions in a day, the session with the highest non-trading probability is the night session for the spot market and morning session for the futures market. We choose to sample the price from each market at 30-second intervals because it results in reasonably low non-trading probabilities.

The choice of 30-second interval assumes that the information transmission between the spot and futures markets takes at least 30 seconds. Comparing the non-trading probability of these two markets gives us some indication of the sampling period. Nevertheless, we also present the results using 1-minute and 3-minute intervals as robustness checks, and they are qualitatively similar to our main result.

[Insert Table 2 Around Here]

4.3 Summary Statistics

We report the descriptive statistics for the data used in our analysis in Table 3. The summary statistics for gold spot trading is reported in Panel A while those for futures trading is reported in Panel B. The gold spot and futures prices declined by 20% during our sample period. Therefore, we expect to see a negative average daily return. The average 30-second log return of the spot market is -0.499×10^{-6}, and that of the futures market is -0.954×10^{-6}. While both the average returns of spot and futures returns are negative, the average 30-second return of the spot market is positive in the afternoon trading session, and the return of the futures market is positive in the afternoon and night trading sessions. Looking at the realized variance (RV) and two-scale realized variance (TSRV), the spot market has higher RV and TSRV compared to the futures market. Furthermore, the night trading session has the highest RV and TSRV, followed by the morning trading session, and the afternoon trading session has the lowest RV and TSRV. This is applicable to both spot and futures markets.

[Insert Table 3 Around Here]

Turning our attention to trading activity, there are on average 1,471 trades per day for the spot market corresponding to an average trading volume of 21,959 contracts. The number of trades and volume are fairly evenly spread across all three trading sessions. The night trading session has the highest number of trades, but it has the lowest number of contracts transacted, indicating that night trading sessions have small trade size. Looking at the futures market, night trading has much higher trading activities in terms of volume and the number of trades. Night trading session trading volume is more than four times that of morning or afternoon sessions. The figures for the three separate trading sessions may not be added up to be the all-day figures because there are only 67 days with night trading session out of the 429 total number of trading days in our sample.

From the summary statistics, we find that the futures market is a more active market with both a higher number of trades and higher volume compared to the spot market. The statistical tests reveal that the number of trades and volume is statistically higher in the futures market in every trading session. Furthermore, we conclude that the futures market has lower return volatility, in terms of RV and TSRV, despite the tests not being significant for the morning trading session. In a cross comparison of the three different trading sessions, the night trading session exhibits high futures market activity and is more volatile relative to the other two sessions. Having said that, higher trading activity does not necessarily correspond to dominance in price discovery. Hauptfleisch et al. (2016) find that the New York gold futures market plays a greater role in price discovery in the gold market despite the London spot market accounting for much higher gold turnover.

5. RESEARCH FINDINGS

5.1 Stationarity and Cointegration Test

Before we determine the cointegration relationship between the spot and the futures markets, we conduct stationarity tests on the gold price series. We implement the Augmented Dickey-Fuller (ADF) test on the price and return series of the spot and the futures markets. The null hypothesis of the ADF test is the presence of unit root in the series, or the series is non-stationary.

Panel A of Table 4 presents the result of ADF test. We fail to reject the null hypothesis for the price series of both spot and futures markets, indicating that the price series are non-stationary. The result is robust to different trading sessions. We carry out the same test on the returns series of the spot and futures markets. We find that both returns series of spot and futures markets are stationary. The null hypothesis of the ADF test is rejected at a 1% significance level for the overall returns series as well as individual trading session series.

[Insert Table 4 Around Here]

Next, we utilize the Johansen (1991) test to determine whether the gold spot and futures price series are cointegrated, and to establish the number of cointegrating vectors. We examine the number of unique cointegration vectors using both the trace and maximum eigenvalue tests. The null hypothesis of $r=0$ cointegration vector is rejected by both of the test statistics except for the night trading session. Furthermore, the null hypothesis of r=1 is not rejected by both of the tests, implying that the system has one cointegrating vector in the price series. The spot and futures contracts should have a common stochastic trend because both of them share the identical underlying asset and arbitrage activity prevents the prices from deviating away from each other.

5.2 Price Discovery of Gold Market

We investigate the contribution of each market to the price discovery process of the gold market in China using three price discovery measures discussed in Section 3. We estimate the information share (*IS*), component share (*CS*), and information leadership share (*ILS*) for every trading day and report the summary statistics for our sample period. Panel A of Table 5 presents the main results. We repeat the analysis for individual trading sessions (morning, afternoon, and night) with results reported in Panels B, C, and D. We report the mean, median, and standard deviation of the respective price discovery obtained from each and every trading day. Furthermore, we report the proportion of trading days that price discovery is dominant on the spot or futures market.

[Insert Table 5 Around Here]

In Panel A of Table 5, the IS attributed to the spot and futures markets are 31.90% and 68.10%, respectively. This indicates that greater gold price discovery occurs in the futures market. The median and proportion numbers show a similar conclusion. Turning to Panel B-C, we find that price discovery occurs in the futures market during all three trading sessions. The difference in IS between the spot and futures market is greatest in the night trading session. The IS attributed to the spot and futures markets during the night trading sessions are 19.40% and 80.60%, respectively. In summary, the result for the IS reveals that the futures market dominates the price discovery of gold in China, and the result is robust to individual trading sessions.

We also provide additional evidence on price discovery using the CS approach. Consistent with the findings using IS, the CS measure reveals that more price discovery occurs in the futures market. The CS attributed to the spot and futures markets are 37.10% and 62.90%, respectively. All three trading sessions have higher CS in the futures market than in the spot market. The CS provides further evidence that the spot market contributes more to the price discovery process; with the magnitude being similar to those of IS.

Finally, we focus on price discovery indicated by the ILS measure. Hasbrouck (1995) define the price discovery as the first security that responses to the material information by changing its price. According to a simulation study conducted by Putnins (2013), ILS is the best measure to capture such immediate responses to permanent price shocks. The ILS reveals a similar result to those obtained using IS and CS, that the price discovery process occurs more in the futures market than in the spot market. The overall ILS for the spot and futures markets are 35.97% and 64.03%, respectively. The results in the different sessions also confirm the dominant role of futures markets across all three trading sessions. All three measures also reveal that the difference in price discovery contribution is greatest in the night trading session. For example, the IS of trading in the gold futures market is 80.60%, while the gold spot market contributes 19.40% of share.

All results indicate that more price discovery occurs in the futures market. The results are consistent with the findings of Hauptfleisch et al. (2016) who state that the New York gold futures market plays a greater role on average in the price discovery process in comparison to the London spot market. Yan and Zivot (2010) compare and contrast IS, CS, and ILS. They argue that IS is a metric that captures both permanent and transitory shocks, while CS responds more to transitory shocks. ILS, on the other hand, responds only to permanent shocks. Using their argument, we can infer that the gold futures market has increased noise as shown by the higher CS. However, the gold futures market is also the place where material information enters the gold market as demonstrated by the higher ILS.

One explanation for the dominant role played by the futures market is the higher liquidity and lower trading cost compared to those of the spot market. In our sample, the number of trades and the trading volume in the gold futures market are indeed higher, with the volume more than four times those of the spot market. We cautiously accept this explanation because higher trading activity does not necessarily explain price discovery dominance.

Furthermore, Chinese spot gold is predominantly used by slower moving longer-term investors seeking safe haven assets, where the physical delivery of gold spot contracts is 38% of the trading volume. On the other hand, futures market predominantly comprises fast-moving speculative and hedge investors, where the physical delivery of contracts is only 0.02% of the total trading volume. The fast-moving investors help the information to disseminate into the market via futures contracts trading.

5.3 Sequential Price Discovery Process

In this section, we study the sequential price discovery of the gold spot market and futures market, respectively. The three different measures are detailed in the previous section and repeated here for a concise comparison. The ratio TSRV/RV measures the market efficiency or the amount of noise in the trading session; IS captures the effective information reflected in the price; and WPC measures the proportion of price change in the trading session out of the daily total price change. We focus most of our inference on the spot market as there are only 67 trading days that have all three trading sessions in the futures markets.

In Table 6, Panel A reports the price discovery and market efficiency of the gold spot market in non-overlapping trading sessions. Since there is no night trading on each Friday prior to May 31, 2013, including the morning and afternoon sessions but not the night session underestimates the IS and WPC in the night session. Therefore, we remove all Friday data before May 31, 2013. First, we examine and compare the market efficiency across three different trading session using ratio TSRV/RV. The ratio has the highest value (95.48%) in the night trading session. While the night trading session is the most efficient and statistically different from the other trading sessions, the differences are not economically different from those of the morning and afternoon trading sessions. The IS is highest in the night trading session with a value of 72.63%. This indicates that the night trading session alone represents 72.63% of the daily price discovery. Statistical tests show that the IS in the night trading session is statistically different from those of the morning and afternoon sessions. WPC also shows similar results to those of IS where the night trading session contributes most of the overall daily price change. The WPC is 61.42% in the night trading session, and the values are approximately 20% for both the morning and afternoon sessions. For the gold spot market, the three trading sessions are equally efficient. However, most of the price discovery happened during the night trading sessions.

[Insert Table 6 Around Here]

In Panel B, we repeat the sequential price discovery for gold spot market using a shorter period that is consistent with the sample period of gold futures market. There are 67 trading days that have all there trading sessions in the gold futures market. The result is very similar to the full sample analysis presented in Panel A. Again, all three trading sessions are equally efficient, but most of the daily price volatilities and price changes are attributed to the night trading.

In Table 7, we analyse the price discovery and market efficiency of the gold futures market in non-overlapping trading sessions. Similar to the result for the gold spot market in Table 6, all three trading sessions of gold futures market have a similar value of TSRV/RV ratio despite them being statistically different from each other. While the morning trading session is the most efficient and statistically different from the other trading sessions, the differences are not economically different from those of the afternoon and night trading sessions. Turning to IS, the night trading session alone contributes 55.20% of the price discovery while the morning and afternoon sessions contribute 26.59% and 18.20%, respectively. Looking at the WPC, the night session alone represents 56.96% of the daily price change, which is higher than those of the afternoon and morning sessions. The result from WPC is consistent with the result from IS, and the futures market result is similar to those of the spot market.

[Insert Table 7 Around Here]

In summary, there is little economic difference in terms of market efficiency across the three trading sessions for both the gold spot and the futures markets. However, the price contribution happens more in the night trading session for both the spot and the futures markets. Apparently, most of the market information is disseminated during the night trading session in China when it is daytime in the U.S. In other words, the higher price discovery contribution in the night trading session is not because of market efficiency in the night session, but higher information intensity during at the time.

5.4 Robustness

In the main section, we sample the gold prices every 30 seconds to construct time-series of returns for gold spot and futures markets. The choice of 30-second interval assumes that the information transmission between the spot and futures markets takes at least 30 seconds. We justify the choice using the non-trading probability in Section 4.2. However, this is not a definite choice of the sampling interval. In this section, we replicate the main price discovery analysis using 1-minute and 3-minute sampling intervals as robustness checks.

In Table 8, we replicate the parallel price discovery between the gold spot and futures markets. Panel A replicates the main results using a 1-minute sampling interval. The IS attributed to the spot and futures markets are 39.78% and 60.22%, respectively. The CS and ILS measures remain at similar levels with IS that more price discovery also occurs in the futures market with the share of 54.89% and 60.03%. The ILS reveals a similar result as those of IS and CS.

Panel B replicates the results using a 3-minute sampling interval. The IS attributed to the spot and futures markets are 49.12% and 50.88%, respectively. Contrary to the finding using IS, the CS reveals that more price discovery occurs in the spot market. The CS attributed to the spot and futures markets are 54.41% and 45.59%, respectively. Finally, we refer to the price discovery analysis using the ILS measure. The ILS reveals a similar result to those uncovered by the IS; that the price discovery process occurs more in the futures market than in the spot market.

According to Yan and Zivot (2010), CS captures only transitory shocks, while IS responses to both permanent and transitory shocks, and ILS captures only permanent shocks. Based on the results above, we conclude that the futures market contributes more to price discovery in the Chinese gold market, but that the contribution from the futures market diminishes over longer interval measure. Furthermore, CS usually gives different result to those of IS and ILS if the sampling period is much longer than the time required for information dissemination.

In comparison with the main analysis that uses 30-second sampling interval, the difference in price discovery shares between spot and futures markets using 1-minute reduces significantly, the difference reduces further and is closer to 50% if the 3-minute interval is used. In unreported analysis, the difference in price discovery shares between spot and futures markets using 10-second data frequency increases significantly. These robustness checks not only confirm that the futures market contributes more to price discovery in the Chinese gold market but also demonstrate that information transmission between the spot and futures markets takes less than three minutes.

Furthermore, we also replicate the sequential price discovery analysis within gold spot and futures markets using 1-minute and 10-second sampling intervals. The finding is qualitatively similar to those of the main analysis.

6. CONCLUSION

This study examines price discovery in the Chinese gold market. The Chinese gold market is becoming increasingly important due to its rapid growth in recent years. It has been the second largest gold spot market and second largest gold futures market in the world since 2013.

We adopt the Vector Error Correction Model framework and apply the information share derived by Hasbrouck (1995), the component share proposed by Gonzalo and Granger (1995), and the information leadership share developed by Putnins (2013) as three main measures of parallel price discovery between the gold spot and gold futures markets. Furthermore, we carry out a sequential price discovery study across morning, afternoon, and night sessions within the gold spot market and the gold futures market. The three main sequential price discovery measures employed are: variance ratio analysis between the two-scale realized variance and realized variance (TSRV/RV); the modified information share measure; and the weighted price contribution (WPC).

We find that price discovery occurs more in the futures market than in the spot market. The result is robust with different price discovery measures, namely information share, component share, and information leadership share. In other words, gold prices in the futures market contains more up-to-date information. Our analysis of sequential price discovery within the spot market and within the futures market reveals that price discovery occurs more in the night trading session for both spot and futures markets.

Our findings have implications to a wide range of investors, including the jewellery industry, commercial banks, and large pension funds with long-term investments. Our results are important to policy makers because they shed light on market design. Most of the studies on price discovery between futures and spot markets demonstrate that most price discovery happens in the futures market, with the most common explanation being that futures contracts are highly leveraged and have lower transaction cost; therefore, the traders with informational advantages choose to trade in the futures market. On the other hand, it is also possible that higher transaction costs, restrictions on trader membership, or the lack of a short-selling facility prevent informed trading from happening in the spot market. In the long-run, good market design will help China achieve a more efficient and internationally integrated gold market.

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Table 1
Trading Volumes of Futures Contracts by Maturing Month

There are 12 futures contracts with different maturity available for trade at any one time in the futures markets. This table presents the trading volume of futures contract by three group of maturing months – contract that matures in June, contract that matures in December, and sum of contracts that mature in all other months. Volume is the total number of contracts traded in the month. Proportion trading volume ratio of the specific contract to the total market volume. Sample period is January 2012 – October 2013.

	June Futures Contract		December Futures Contract		Other Months Futures Contract	
Month	Volume	Proportion	Volume	Proportion	Volume	Proportion
Jan 2012	69,447	**98.2%**	1,032	1.5%	229	0.3%
Feb 2012	49,618	**96.7%**	1,576	3.1%	132	0.3%
Mar 2012	47,680	**92.6%**	3,659	7.1%	145	0.3%
Apr 2012	14,778	31.7%	31,611	**67.9%**	188	0.4%
May 2012	1,229	2.1%	56,375	**97.5%**	205	0.4%
Jun 2012	68	0.1%	53,847	**99.3%**	293	0.5%
Jul 2012	110	0.2%	46,036	**99.4%**	161	0.3%
Aug 2012	407	1.0%	38,705	**98.6%**	136	0.3%
Sep 2012	2,627	5.1%	48,564	**94.4%**	278	0.5%
Oct 2012	9,587	23.8%	30,215	**75.1%**	420	1.0%
Nov 2012	32,671	**85.4%**	5,281	13.8%	306	0.8%
Dec 2012	42,900	**99.0%**	143	0.3%	305	0.7%
Jan 2013	33,042	**98.8%**	191	0.6%	205	0.6%
Feb 2013	32,170	**96.4%**	1,007	3.0%	194	0.6%
Mar 2013	31,014	**93.8%**	1,923	5.8%	142	0.4%
Apr 2013	56,974	**64.5%**	30,926	35.0%	485	0.5%
May 2013	8,443	7.9%	98,225	**91.7%**	505	0.5%
Jun 2013	521	0.6%	87,129	**98.8%**	538	0.6%
Jul 2013	220	0.1%	310,357	**99.7%**	588	0.2%
Aug 2013	991	0.3%	395,261	**99.5%**	1,033	0.3%
Sep 2013	2,216	0.9%	238,573	**98.8%**	755	0.3%
Oct 2013	5,109	2.2%	231,562	**97.5%**	911	0.4%

Table 2
Trading Frequencies and Non-Trading Probabilities

This table reports the trading frequencies and non-trading probabilities for the different time intervals in the Chinese gold spot market (Panel A) and gold futures market (Panel B). Each trading day is divided into multiple of fixed time intervals. The first column is the time interval and it ranges from 10 seconds to 15 minutes. The second column presents the average number of trades in the specific fixed time interval. The last four columns present the non-trading probability in the gold markets for the corresponding time interval in the respective trading sessions (morning, afternoon, night, and whole day). The sample period is January 2012 – October 2013.

Panel A: Gold Spot

Interval	Trading Frequency	Non-Trading Probability (%)			
		Morning	Afternoon	Night	All
10-second	0.52	63.4%	54.4%	69.7%	60.7%
30-second	1.56	32.2%	21.7%	44.5%	29.8%
1-minute	3.12	14.6%	7.3%	28.6%	13.7%
2-minute	6.22	4.2%	1.4%	15.9%	4.7%
3-minute	9.35	1.7%	0.4%	10.3%	2.3%
5-minute	15.58	0.4%	0.1%	4.8%	0.9%
10-minute	30.63	0.0%	0.0%	1.7%	0.2%
15-minute	46.62	0.0%	0.0%	0.6%	0.1%

Panel B: Gold Futures

Interval	Trading Frequency	Non-Trading Probability (%)			
		Morning	Afternoon	Night	All
10-second	3.97	10.1%	6.6%	7.2%	8.5%
30-second	11.90	1.2%	0.6%	0.9%	1.0%
1-minute	23.80	0.3%	0.2%	0.1%	0.2%
2-minute	47.44	0.1%	0.1%	0.0%	0.1%
3-minute	71.36	0.1%	0.0%	0.0%	0.1%
5-minute	118.87	0.1%	0.0%	0.0%	0.0%
10-minute	233.67	0.0%	0.0%	0.0%	0.0%
15-minute	355.65	0.0%	0.0%	0.0%	0.0%

Table 3
Summary Statistics of Gold Spot and Futures Trading

This table reports the summary statistics of average return, realized variance (RV), two-scale realized variance (TSRV), the daily number of trades, and daily trading volume for gold spot trading (Panel A) and gold futures trading (Panel B). The return is sampled at the 30-second interval. RV and TSRV are calculated from the sampled return on a daily basis. The summary statistics are calculated using full day trading or divided the full day into three trading sessions (morning, afternoon, and night). The last column of Panel B conducts the statistical test between the variables in spot and futures markets. The sample period is January 2012 – October 2013.

Panel A: Gold Spot

		N	Mean	Std	P5	P25	Median	P75	P95
Return	All	465,413	-0.499	348.114	-306.138	0.000	0.000	0.000	306.513
($\times 10^6$)	Morning	128,699	-0.400	411.667	-263.897	0.000	0.000	0.000	267.415
	Afternoon	102,720	0.672	203.109	-272.438	0.000	0.000	0.000	272.831
	Night	233,994	-1.068	360.157	-365.698	0.000	0.000	0.000	364.100
RV	All	429	89.696	133.112	7.217	31.816	59.743	104.575	240.564
($\times 10^6$)	Morning	429	12.068	18.556	1.624	3.490	6.447	13.426	36.024
	Afternoon	428	8.459	11.877	1.189	2.561	5.002	9.446	27.142
	Night	354	57.045	73.964	11.446	26.187	40.602	63.225	147.390
TSRV	All	429	85.238	125.533	6.915	30.327	57.311	99.386	229.718
($\times 10^6$)	Morning	429	11.332	17.249	1.564	3.265	6.054	12.480	33.172
	Afternoon	428	7.984	11.206	1.141	2.423	4.724	9.003	25.125
	Night	354	53.999	67.983	10.937	25.205	39.102	60.895	136.987
Daily Trades	All	429	1,471	649	707	1,027	1,338	1,710	2,738
	Morning	429	447	228	202	296	395	527	875
	Afternoon	428	461	177	258	351	423	532	796
	Night	354	683	358	280	440	600	812	1,458
Daily Volume	All	429	21,959	10,691	9,918	14,678	19,428	26,340	41,832
	Morning	429	7,388	4,697	2,372	4,194	6,042	9,308	16,082
	Afternoon	428	8,270	4,079	3,786	5,638	7,232	9,897	15,984
	Night	354	7,659	5,002	2,650	4,558	6,569	9,192	15,852

Panel B: Gold Futures										
		N	Mean	Std	P5	P25	Median	P75	P95	t-stat (Futures≠Spot)
Return	All	237,336	-0.954	501.851	-315.624	-89.372	0.000	89.667	319.268	(-1.08)
($\times 10^6$)	Morning	115,829	-2.380	646.304	-290.436	-85.038	0.000	85.204	298.187	(-1.16)
	Afternoon	77,220	0.169	238.136	-288.642	-87.146	0.000	87.548	286.258	(-0.44)
	Night	44,287	0.820	397.914	-380.662	-180.783	0.000	182.465	381.025	(0.19)
RV	All	429	36.812	77.355	3.81	6.659	10.43	29.16	142.463	(-5.65)***
	Morning	429	11.304	16.478	2.143	3.666	5.89	13.429	36.493	(-0.80)
	Afternoon	429	6.723	8.722	1.322	2.264	3.573	7.428	22.965	(0.02)
	Night	67	44.781	28.381	20.339	27.164	37.326	51.923	98.154	(6.35)***
TSRV	All	429	34.568	73.342	3.581	6.253	9.751	27.799	132.502	(-9.14)***
	Morning	429	10.614	15.72	2.017	3.427	5.613	12.074	33.774	(-1.09)
	Afternoon	429	6.249	8.222	1.242	2.119	3.339	7.06	21.441	(-4.24)***
	Night	67	40.509	27.234	17.595	24.215	33.056	47.106	91.899	(-6.59)***
Daily Trades	All	429	7,231	4,349	3,436	4,475	5,602	7,897	17,096	(29.47)***
	Morning	429	3,284	1,225	1,886	2,533	3,023	3,719	5,589	(53.8)***
	Afternoon	429	2,427	873	1,398	1,826	2,289	2,817	3,916	(53.3)***
	Night	67	9,733	2,026	6,536	8,508	9,444	11,298	13,820	(41.03)***
Daily Volume	All	429	92,862	111,711	23,936	33,802	46,118	76,802	384,992	(13.67)***
	Morning	429	33,714	21,190	12,966	19,148	27,344	42,326	80,904	(29.53)***
	Afternoon	429	24,026	15,643	9,602	13,380	19,328	28,244	57,656	(23.4)***
	Night	67	224,886	85,354	109,172	161,990	213,008	279,450	386,128	(21.48)***

Table 4
Stationarity and Cointegration Tests

Panel A presents Augmented Dickey-Fuller stationarity (ADF) test on the natural logarithm of price level and its first difference (return). The null hypothesis is the presence of unit root in the data. Values in the parenthesis are the Ljung-Box (1999) p-values. Panel B presents the results from Johansen (1991) test for a number of unique cointegrating relationships where r represents the number of cointegrating vectors on the Chinese gold spot market and gold future market price series. The Johansen (1991) test requires the testing hypotheses of at most zero or one cointegrating vectors using trace or maximum eigenvalue tests. Values in the parenthesis are the MacKinnon-Haug-Michelis (1999) p-values. The tests are conducted using full day trading or dividing the full day into three trading sessions (morning, afternoon, and night). The Sample period is January 2012 – October 2013.

Panel A: Augmented Dickey-Fuller Stationary Test

	All	Morning	Afternoon	Night
Variable	ADF	ADF	ADF	ADF
Spot (log prices)	-2.035	-2.103	-2.146	-2.178
	(0.58)	(0.54)	(0.52)	(0.50)
Spot (returns)	-755.103	-189.405	-239.776	-525.579
	(0.00)	(0.00)	(0.00)	(0.00)
Futures (log prices)	-2.225	-2.064	-2.148	-1.922
	(0.48)	(0.57)	(0.52)	(0.64)
Futures (returns)	-356.317	-364.311	-294.141	-144.174
	(0.00)	(0.00)	(0.00)	(0.00)

Panel B: Cointegration Analysis

	All		Morning		Afternoon		Night	
Rank	Trace	Max. Eigen	Trace	Max. Eigen	Trace	Max. Eigen	Trace	Max. Eigen
H_0: r = 0	135.374	129.642	82.501	76.642	65.147	58.979	76.587	71.081
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
H_0: r = 1	5.731	5.731	5.859	5.859	6.167	6.167	5.505	5.505
	(0.50)	(0.50)	(0.48)	(0.48)	(0.44)	(0.44)	(0.53)	(0.53)

Table 5
Price Discovery of Chinese Gold Market

This table presents the result of price discovery on Chinese gold market using three price discovery measures. The three price discovery metrics are Information Share (IS), Component Share (CS), and Information Leadership Share (ILS). The estimates are in percentage term and are calculated from a vector error-correction model containing only one common factor and estimated using the 30-second-by-30-second prices of the spot and futures markets. The price discovery is estimated for each and every trading day, and the mean, median, and standard deviation of the price discovery measures are reported. Proportion is the proportion of day that the price discovery occurs more in that specific market. Panel B, C, and D provide similar analyses using data from different trading sessions within a day. The sample period is January 2012 – October 2013.

Panel A: Price Discovery in All Overlapping Trading Periods

	Information Shares		Components Shares		Information Leadership	
	Spot	Futures	Spot	Futures	Spot	Futures
Mean	31.90%	68.10%	37.10%	62.90%	35.97%	64.03%
Median	22.84%	77.16%	31.67%	68.33%	32.72%	67.28%
Std.	27.43%	27.43%	24.87%	24.87%	25.23%	25.23%
Proportion	24.57%	75.43%	30.47%	69.53%	26.54%	73.46%

Panel B: Price Discovery in Morning Trading Session

	Information Shares		Components Shares		Information Leadership	
	Spot	Futures	Spot	Futures	Spot	Futures
Mean	33.60%	66.40%	40.32%	59.68%	33.09%	66.91%
Median	24.98%	75.02%	37.67%	62.33%	27.64%	72.36%
Std.	29.22%	29.22%	24.94%	24.94%	25.77%	25.77%
Proportion	26.42%	73.58%	31.11%	68.89%	22.72%	77.28%

Panel C: Price Discovery in Afternoon Trading Session

	Information Shares		Components Shares		Information Leadership	
	Spot	Futures	Spot	Futures	Spot	Futures
Mean	32.82%	67.18%	42.36%	57.64%	30.92%	69.08%
Median	25.59%	74.41%	42.08%	57.92%	25.18%	74.82%
Std.	28.81%	28.81%	25.56%	25.56%	26.15%	26.15%
Proportion	27.37%	72.63%	38.16%	61.84%	20.79%	79.21%

Panel D: Price Discovery in Night Trading Session

	Information Shares		Components Shares		Information Leadership	
	Spot	Futures	Spot	Futures	Spot	Futures
Mean	19.40%	80.60%	24.01%	75.99%	30.84%	69.16%
Median	11.13%	88.87%	18.38%	81.62%	29.20%	70.80%
Std.	21.13%	21.13%	17.96%	17.96%	23.33%	23.33%
Proportion	10.61%	89.39%	7.58%	92.42%	16.67%	83.33%

Table 6
Spot Market Price Discovery and Market Efficiency in Different Trading Sessions

This table presents the price discovery and compares the market efficiency in three different trading sessions for the gold spot market. There are three non-overlapping trading sessions in a trading day: Morning, Afternoon, and Night. The ratio TSRV/RV is used as a measure of market efficiency. TSRV or two-scale realized variance is a measure of information flow; RV or realized variance is a measure price volatility that is contributed by both information and microstructure noise. Information share is the measure of price discovery. TSRV/RV and Information share are obtained daily, and the reported numbers are the average figures across all trading days. Statistical tests are conducted to examine the differences of TSRV/RV or Information share between different trading sessions. WPC or weighted price contribution is an alternated measure of price discovery across non-overlapping trading sessions. The WPC is calculated for the full sample. In Panel A, the Friday data before May 31, 2013 is removed from the analysis because there is no night trading session on Friday before May 31, 2013. The sample period is January 2012 – October 2013. In Panel B, the data are common across both spot and futures market, using the trading period of futures market as the benchmark. The sample period is July 2013 – October 2013.

Panel A: Price Discovery in Different Trading Session (All Trading Days)

	TSRV/RV	Information Shares	WPC
Morning	94.73%	16.00%	20.31%
Afternoon	94.93%	11.36%	18.27%
Night	95.48%	72.63%	61.42%
Night > Morning (t-stat)	(5.83)***	(42.37)***	
Night > Afternoon (t-stat)	(6.14)***	(53.47)***	
Afternoon > Morning (t-stat)	(1.69)**	(-7.26)	

Panel B: Price Discovery in Different Trading Session (July 5, 2013 – October 18, 2013)

	TSRV/RV	Information Shares	WPC
Morning	94.34%	19.68%	17.62%
Afternoon	94.87%	16.29%	16.95%
Night	95.01%	64.03%	65.43%
Night > Morning (t-stat)	(2.82)***	(14.51)***	
Night > Afternoon (t-stat)	(0.85)	(17.45)***	
Afternoon > Morning (t-stat)	(2.39)***	(-2.13)	

Table 7
Futures Market Price Discovery and Market Efficiency in Different Trading Sessions

This table presents the price discovery and compares the market efficiency in three different trading sessions for the gold futures market. There are three non-overlapping trading sessions in a trading day: Morning, Afternoon, and Night. The ratio TSRV/RV is used as a measure of market efficiency. TSRV or two-scale realized variance is a measure of information flow; RV or realized variance is a measure price volatility that is contributed by both information and microstructure noise. Information share is the measure of price discovery. TSRV/RV and Information share are obtained daily, and the reported numbers are the average figures across all trading days. Statistical tests are conducted to examine the differences of TSRV/RV or Information share between different trading sessions. WPC or weighted price contribution is an alternated measure of price discovery across non-overlapping trading sessions. The WPC is calculated for the full sample. The sample period is July 2013 – October 2013.

	TSRV/RV	Information Shares	WPC
Morning	90.44%	26.59%	29.76%
Afternoon	89.10%	18.20%	13.28%
Night	89.24%	55.20%	56.96%
Night > Morning	(-3.13)	(10.69)***	
Night > Afternoon	(0.29)	(15.23)***	
Afternoon > Morning	(-3.04)	(-5.08)	

Table 8
Robustness

This table replicates the result presented in Panel A of Table 5 using alternative return sampling interval. In Panel A, the return is sampled at the 1-minute interval. In Panel B, the return is sampled in the 3-minute interval. The three price discovery metrics are Information Share (IS), Component Share (CS), and Information Leadership Share (ILS). The estimates are in percentage term and are calculated from a vector error-correction model containing only one common factor and estimated using the minute-by-minute prices of the spot and futures markets. The price discovery is estimated for each and every trading day, and the mean, median, and standard deviation of the price discovery measures are reported. Proportion is the proportion of day that the price discovery occurs more in that specific market. The sample period is January 2012 – October 2013.

Panel A: Price Discovery with 1-Minute Sampling Interval

	Information Shares		Components Shares		Information Leadership	
	Spot	Futures	Spot	Futures	Spot	Futures
Mean	39.78%	60.22%	45.11%	54.89%	39.97%	60.03%
Median	35.70%	64.30%	41.63%	58.37%	37.33%	62.67%
Std.	27.90%	27.90%	27.09%	27.09%	26.52%	26.52%
Proportion	33.93%	66.07%	39.85%	60.15%	33.93%	66.07%

Panel B: Price Discovery with 3-Minute Sampling Interval

	Information Shares		Components Shares		Information Leadership	
	Spot	Futures	Spot	Futures	Spot	Futures
Mean	49.12%	50.88%	54.41%	45.59%	42.13%	57.87%
Median	49.12%	50.88%	54.65%	45.35%	39.82%	60.18%
Std.	26.04%	26.04%	27.73%	27.73%	30.58%	30.58%
Proportion	49.16%	50.84%	58.15%	41.85%	40.17%	59.83%

Table A1
Gold Traded on Commodity Exchanges

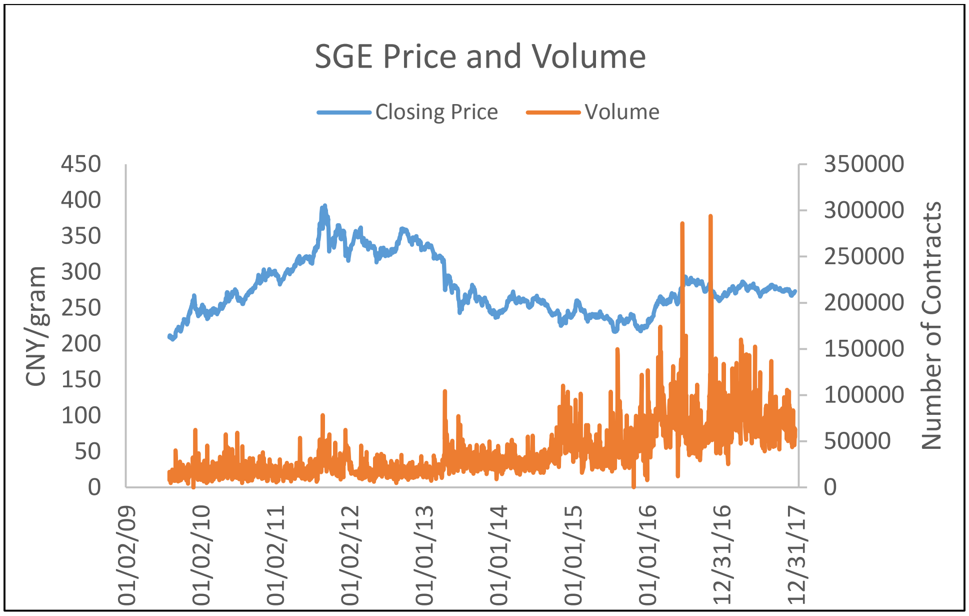
This table summarizes the annual trading volume in terms of weight for all the gold contracts traded on the major commodity exchanges from 2010 and 2016. The volume includes all gold spots and gold derivatives contracts transacted. The source of the table is from Reuters's (2016) GFMS gold survey report and London OTC Market website. Total volume in nominal tons equivalent.

	2010	2011	2012	2013	2014	2015	2016	2016/2010
London OTC Market	143,894	162,379	155,129	172,046	143,437	139,910	152,973	1.06
COMEX (New York)	139,125	152,939	136,522	147,093	126,028	130,135	179,047	1.29
Shanghai Futures Exchange	3,397	7,222	5,917	20,088	23,858	25,317	34,760	10.23
Shanghai Gold Exchange	2,857	3,618	3,063	5,350	7,576	12,044	15,492	5.42
Tokyo Commodity Exchange	12,198	15,194	11,895	12,225	8,745	7,928	8,541	0.70
Multi Commodity Exchange	13,577	15,382	10,324	8,945	3,972	3,947	4,094	0.30

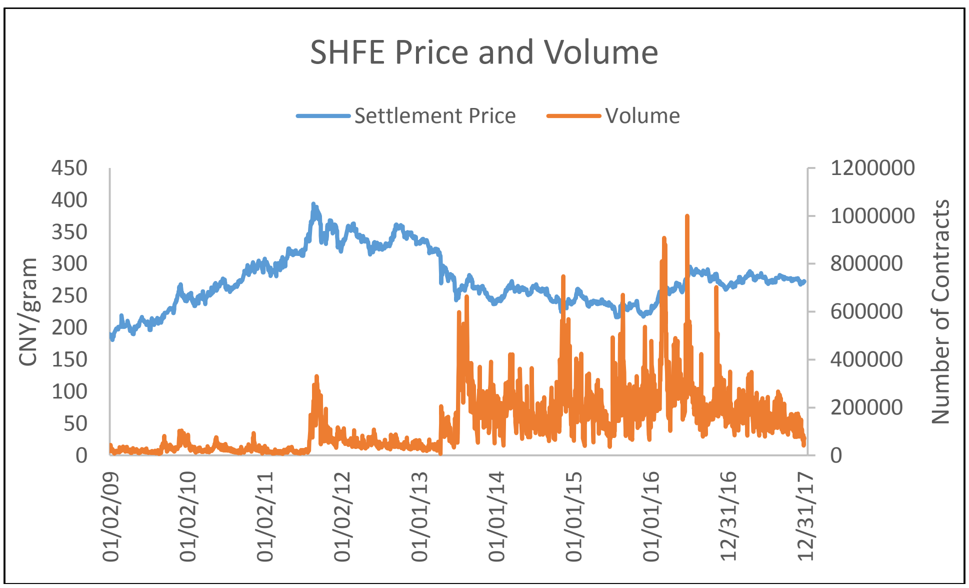
Table A2
Key Features of Gold Spot and Futures Contracts in China

This table summarizes the key features in contract specifications and market structures of the Chinese gold spot and futures markets.

	Spot	Futures
Product Symbol	AU (T+D)	AU
Trading Venue	Shanghai Gold Exchange	Shanghai Futures Exchange
Trading Hours	Monday to Friday 9:00am － 11:30am 1:30pm － 3:30pm 9:00pm － 2:30am (except Friday before 5/31/2013)	Monday to Friday 9:00am － 11:30am 1:30pm － 3:00pm 9:00pm － 2:30am (from 7/5/2013)
Contract Size	1000g per board lot	1000g per board lot
Price Quotation	Chinese Yuan (CNY) per gram	Chinese Yuan (CNY) per gram
Minimum Fluctuation	CNY 0.01 per gram	CNY 0.01 per gram
Daily Price Fluctuation Limit	No more than ± 7% of the previous day's settlement price.	No more than ± 5% of the previous day's settlement price.
Minimum Trading Deposit	15%- 20% of the contract value	7% of the contract value
Termination of Trading	Every trading day	15th day of the delivery month
Listed Contracts	n/a	January to December
Settlement	Physical	Physical
Delivery Period		5 business day after the last trading day
Grade and Quality Specifications	Gold delivered under this contract shall assay to a minimum of 995 fineness	Gold delivered under this contract shall assay to a minimum of 995 fineness
Extension Cost	Unilateral commission 0.13%, 0.02% of the contract value per day. Daily payment according to the business day	Futures companies charge CNY 40 per lot, and exchange charges 0.02% of transaction amount



(a) Trend on SGE



(b) Trend on SHFE

Figure A1. SGE and SHFE Price and Volume