**Global Information Distribution in**

**the Gold OTC Markets**
Edwina F.L.Chaia, Adrian D. Leea, Jianxin Wanga,[[1]](#footnote-1)\*

March 2015

a Finance Discipline Group, University of Technology Sydney, Sydney NSW 2007, AUSTRALIA

**ABSTRACT**

This paper aims to estimate the global information distribution in the OTC gold market. Using the two-scale realized variance as a proxy for information flow, we estimate the information shares of Asia, Europe, London/New York and the United States, with London/New York covering the two-hour overlapping trading in London afternoon and New York morning. We find that over the sample period of 1996 to 2012, the average daily information shares are 17%, 31%, 22%, and 30% for Asia, Europe, London/New York and U.S., respectively. On a per-hour basis, the information share of London/New York is over two and half times of those of the rest of Europe and U.S., and over five times of the information share of Asia. Despite doubling its share of OTC trading, Asia’s information share actually declined from about 20% in the late 1990s to around 15% in 2009-2012, with the opposite trend for the London/New York market. Private information flow, measured by the volatility impact of unexpected order flows, has a flatter distribution across Asia, Europe, and U.S., possibly due to the presence of the same large gold dealers in different markets. The declining information share of Asia and the concentration of information to the two-hour London/New York trading raise concerns for regional market development and global market stability.

Keywords: gold; over-the-counter; price discovery; information share; information concentration, market development

JEL classification: G14; G15; C32

1. Introduction

According to the London Bullion Market Association, “the global bullion market is based on expertise and liquidity in London."[[2]](#footnote-2) The morning and afternoon fixings by the London Gold Fixing Company have been widely used as the benchmark price for almost 100 years. End-users, investors, and central banks around the world use the London fixing price to settle gold transactions, physical or financial. However in the past two decades, the landscape of the global financial markets has changed significantly largely due to new technologies for information transmission and processing. Equity and bond trading has moved away from the traditional exchanges such as the New York Stock Exchange and the London Stock Exchange to networks of trading venues catering to institutional investors trading at fast speed. This decentralization of trading venues has a significant impact on investor behavior and welfare as well as on market regulation. In the global gold markets, there are two noteworthy trends started in the past decade. The first is the financialization of gold and other commodities. Trading of gold ETFs has risen sharply since 2005, mostly in the United States but also in Asia (Figure 1a). The second is the rise of China as a significant market for gold-related financial products. The combined volumes on the Shanghai Gold Exchange and the Shanghai Futures Exchange have long passed the combined volumes on the Tokyo Commodity Exchange and NYSE Liffe, and are second only to the Commodity Exchange in New York.[[3]](#footnote-3) Have these trends made a significant impact on the landscape of global gold trading? Is London still the global center of gold trading and pricing?

While many industry bodies provide statistics on the global distribution of gold-based financial products and trading activities, this paper provides a new perspective on the global structure of the gold market. We estimate the global distribution of price-relevant information in the global over-the-counter (OTC) market for spot gold and examine how this distribution has shifted since mid-1990s. An empirical measure of global information distribution can be a valuable tool for investors and market regulators. It can shed light on the questions raised above and lead to a new understanding of the global gold market. Is the global distribution of information the same as the global distribution of trading volume? Does the rise in gold ETF trading represent a shift in the global information distribution? Does the rising volume in spot gold and derivative trading in Asia indicate that markets in Asia have greater information flow and pricing power than before?

While the perspective is on the global or macro structure, our analyses are based on methodologies developed in the market microstructure literature. A key focus of the literature is the price discovery process that incorporates new information into the asset prices. Several methods have been proposed to estimate the distribution of price discovery across different trading venues. They have been adopted to examine a wide range of issues and have become “a mid-size cottage industry” ([Lehmann (2002](#_ENREF_26))). These measures have found their way into studies of gold markets. [Zhang (2005](#_ENREF_41)) and [Fuangkasem, Chunhachinda and Nathaphan (2012](#_ENREF_19)) show that futures exchanges in other regions are gaining price discovery. [Lucey, Larkin and O'Connor (2013](#_ENREF_28)) report that London and New York have similar information shares and there is no evidence of shifting information distribution. [Ivanov (2011](#_ENREF_23)) finds evidence of price discovery shifting from gold futures to gold ETFs. Since price discovery is defined as the process of incorporating new information, the price discovery measures are measures of information flows. These and other studies of price discovery provide empirical evidence on information flows in the global market for gold.

This study has three distinct features from existing studies of gold market price discovery. First, we provide a comprehensive overview of information distribution across the 24-hour market, and examine how the global information distribution has shifted over the period from 1996 to 2012. The global 24-hour market is divided into four regional markets of Asia, Europe, London/New York and the United States. Asia, Europe, and the U.S. represent different geographic regions and time zones. The London/New York market is the two-hour overlapping period between afternoon trading in London and morning trading in New York City.[[4]](#footnote-4) New York is the global hub for trading a wide range of financial products whose values often have implications for the price of gold. The two hours cover the London afternoon fixing at 3 pm London time which is an important benchmark price for gold. It is likely that these two hours are more informationally intensive than periods when London or New York is trading alone. Wang and Yang (2011) show that these two hours have the highest information share per hour across global currency markets.

Second, our study is based on price discovery measures suitable for non-overlapping sequential markets. The price discovery measures of [Hasbrouck (1995](#_ENREF_21)) and [Harris, McInish and Wood (2002](#_ENREF_20)) are designed for parallel markets where trading takes place simultaneously. They cannot be applied to markets with little or no overlapping trading hours, e.g. Tokyo and London or Shanghai and New York. We use a price discovery measure of [Wang and Yang (2011](#_ENREF_39)) which is designed for non-overlapping sequential markets. The non-parametric measure is in the spirit of Hasbrouck (1995), where information flow is measured by the variance of the unobservable efficient price. Using 5-minute and 1-minute intraday prices, we construct the two-scale realized variance (TSRV) proposed by [Zhang, Mykland and Aït-Sahalia (2005](#_ENREF_42)). TSRV removes the noise component associated with high-frequency return autocorrelation, thus capturing the true innovation in returns. As a robustness check, we also estimate information distribution using the popular weighted price contribution (WPC).

Third, we estimate private information flows embedded in the order flows in each market. This provides new evidence on the cross-market differences, as well as further refinement on the overall information distribution. In microstructure studies, a widely adopted assumption is that private information comes through order flows and transactions, while public information directly leads to quote revisions. Various measures of information asymmetry, e.g. the spread component models and the probability of informed trading (PIN), are based on the sequence of order flows or the imbalance between buy and sell orders.[[5]](#footnote-5) Given the strong evidence in the literature, we adopt this approach to measure private information flow as the component of TSRV determined by the unexpected trades and order imbalance. We recognize that order flow is not the only channel through which private information is incorporated into price. For example, quote changes may also reflect private information of the posting dealer. Our estimates can be regarded as a lower bound of private information flow in each market.

We report several new empirical findings on price discovery and information flow in the gold OTC markets over the sample period of 1996 to 2012:

* Over the sample period of 1996 to 2012, the information shares in the global OTC trading of spot gold are 17%, 31%, 22%, and 30% for Asia, Europe, London/New York, and U.S. respectively. On a per-hour basis, the information shares are 2.1%, 4.4%, 11%, and 4.3% respectively. Clearly trading in Asia has the least information content, and trading during the 2-hour London/New York period has the highest information content.
* The global trading volume distribution is very different from the global information distribution. For example, Asia accounts for 22% of global OTC spot trades and the two-hour London/New York period has 15% of OTC spot trades, both are very different from their information shares.
* The surge in trading volumes in Shanghai has not increased Asia’s share in global information flow. In fact, despite doubling its share of OTC trades from around 10% in the late 1990s to 22% since 2007, Asia’s information share has experienced a significant decline from an average of 20.3% in 1996-1999 to an average of 14.8% in 2009-2012. To the contrary, the average information share of the London/New York market has increased from 18% in 1996-1999 to 22.8% in 2009-2012. The finding is somewhat surprising and deserves further investigation. One possible explanation is that the gold market may have experienced the same consolidation as in the OTC foreign exchange markets, with the top five FX dealing banks accounting for 80% of interbank trading (e.g. [Wallace (2014](#_ENREF_38))). The concentration of trading and pricing power to a few mega banks in London and New York may help explain their rising information share at the expense of new markets in Asia.
* Europe and the United States, excluding the two-hour London/New York overlapping period, have almost equal information shares at around 30%. If the 22% information share for overlapping hours is split equally between the two cities, they each have around 41% information share, ignoring the contributions of other cities in Europe and U.S. The finding is consistent with that of [Lucey, Larkin and O'Connor (2013](#_ENREF_28)). It does not support the claim by the LBMA that the global gold market is based on the expertise in London.
* As in many studies, we find significant information spillover across markets. For markets other than Asia, the strongest spillover comes from the market that immediately precedes its trading: Europe has a strong spillover to London/New York, which in turn has a strong spillover to U.S. We also find that volatility in each market has significant dependence on its own lagged value 24 hours ago. Such self-dependence is the strongest in Asia. This self-dependence is present after controlling for information flow captured by volatilities in previous markets in the 24-hour cycle or by the contemporaneous order flows in the local market. We argue that it is unlikely to be driven by long-lived private information (more than 24 hours), and more likely to be driven by the local market characteristics such as the mix of individual and institutional investors, their risk tolerance, etc.
* The order flow-based estimation of private information shows that the two-hour London/ New York trading has 24% of daily private information flow, higher than its 22% share of the overall information flow. The distribution of private information is relatively flat for the other markets. The shares of private information are 21.6%, 27.6%, and 26.8% for Asia, Europe, and U.S. respectively. The flatter distribution of private information may reflect the presence of the same global dealers, mostly investment banks, in different markets. Asia still has a very low per-hour private information share at 2.7%, compared to almost 4% for Europe and U.S. and 12% for London/New York.

The rest of the paper is organized as follows. Section II discusses some trends in the gold market in the sample period. Section III explains our measures for information flows. Section IV presents the data and the estimated global information distribution. Section V estimates volatility spillovers and private information flows. Section VI concludes.

1. Recent Trends in the Gold Market

Since the turn of the century, the global gold market has experienced two important changes. The first is the rise of the exchange-traded funds (ETFs) on gold, mostly in the United States but also in Asia.[[6]](#footnote-6) Europe appears to have a very small share of the gold ETFs (Figure 1a). The physical (allocated) ETFs are backed by holdings of bullion, thus increasing demand for spot gold. The synthetic ETFs are backed by gold derivatives and do not directly impact demand for spot gold. Because of their low transaction costs and high liquidity, “[T]he introduction of ETFs on gold leads to a structural demand shift” ([Baur (2013](#_ENREF_5))). There is a strong correlation between the number of gold ETFs and the gold price (Figure 1b). [Ivanov (2011](#_ENREF_23)) shows evidence that gold price discovery moves away from futures trading to ETFs in the United States. We examine whether the trading of gold ETFs in the United States has increased its information share in the gold OTC market.

[INSERT FIGURE 1A AND 1B HERE]

The second trend in the gold market is the rise of Asia, and China in particular, in gold demand. Figure 2a shows that China and India account for over half of the global gold demand. Figure 2b shows a striking positive correlation between China’s share of gold demand and the gold price. The Shanghai Futures Exchange started trading gold futures in 2008 and is the second largest gold futures market after COMEX ([Thomson Reuters (2014](#_ENREF_37))). Together with the Shanghai Gold Exchange, Shanghai now accounts for 23% of gold traded on the global commodity exchanges and launched two gold ETFs in 2013. With the decline of the Tokyo Commodity Exchange (trading volume decreased by 20% between 2011 and 2013 ([Thomson Reuters (2014](#_ENREF_28))), Shanghai is poised to become a major hub in Asia for gold trading and information.

[INSERT FIGURE 2A AND 2B HERE]

1. Measuring Information Flow and Distribution

Most existing price discovery measures are designed for parallel markets in which there is only one true price at any time. In this case, risk-free arbitrage leads to a co-integrating price relationship across parallel markets, which is at the center of the models of [Hasbrouck (1995](#_ENREF_21)) and [Harris, McInish and Wood (2002](#_ENREF_20)). This study differs from most studies of price discovery in that we divide a 24-hour trading day into 4 non-overlapping markets. Since new information in one market can lead to large price changes from the previous market, the cross-market co-integration relationship no longer holds. Therefore the measures of Hasbrouck (1995) and [Harris, McInish and Wood (2002](#_ENREF_20)) cannot be applied to the 24-hour sequential market setting.

To measure information flow in non-overlapping sequential markets, Wang and Yang (2011) proposes the following model in the spirit of Hasbrouck (1995). A trading day *t* is divided into *n* non-overlapping sequential markets. The log price in market *i* on day *t* can be written as p*i,t* = m*i,t* + u*i,t*, where m*i,t* is the unobservable efficient price and u*i,t* is a noise term. Therefore the log return is given by r*i,t =* Δp*i,t =* Δm*i,t +* Δu*i,t*. By definition the change in efficient price reflects the arrival of new information, therefore Δm*i,t* is serially uncorrelated. The noise term Δu*i,t* captures the serial correlation in returns. Information flow in market *i* is defined as the variation of the efficient price in market *i* and is captured by the variance of Δm*i,t*. The information share (IS) of market *i* is given by $IS\_{i}=\frac{var(Δm\_{i,t})}{\sum\_{j=1}^{n}var(Δm\_{j,t})}$. To measure var(Δmi,t), [Wang and Yang (2011](#_ENREF_39)) suggest using the two-scale realized variance (TSRV) of [Zhang, Mykland and Aït-Sahalia (2005](#_ENREF_42)). TSRV removes the return noise that is serially correlated over time and is a consistent estimator of the true integrated variance driven by information.

[Barndorff-Nielsen *et al.* (2008](#_ENREF_4)) show that the *k*-subsampling TSRV on a trading day *t* for market *i* is given by:

|  |  |
| --- | --- |
| $TSRV\_{i,t}=\frac{1}{k}\sum\_{j=1}^{k}RV\_{i,t,j}-\frac{m-k+1}{mk}RV\_{i,t} $  | (1) |

The variables are defined as:

* *m* is the number of intraday intervals. In our case, m is the number of 1-minute intervals for each 8-hour market, i.e. *m* = 480.
* $RV\_{i,t}=\sum\_{s=1}^{m}r\_{i,t,s}^{2}$ and r*i,t,s* is the 1-minute return in interval *s*.
* *k* is the number of sub-grids on 1-minute grid. We resample at 5-minute intervals, therefore *k* = 5. Each resampling *j* starts at a different 1-minute grid.
* RV*i,t,j* is the *j*th RV based on 5-minute resampling, each *j* starting from a different 1-minute grid.

Theorem 6 of [Barndorff-Nielsen *et al.* (2008](#_ENREF_4)) shows that:

|  |  |
| --- | --- |
| $TSRV\_{i,t}=\left(1-\frac{m-k+1}{mk}\right)\hat{γ}\_{i,t,0}+\sum\_{h=1}^{k}\frac{k-h}{k}(\hat{γ}\_{i,t,-h}+\hat{γ}\_{i,t,h})-\frac{1}{k}R\_{k}$  | (2) |

Here $\hat{γ}\_{i,t,\pm h}≡\sum\_{s=1}^{m-h}r\_{i,t,s}r\_{i,t,s+h}$ for *h* = 0, 1, …, *m-1*. Clearly $\hat{γ}\_{i,t,0}$ = RV*i,t* and $\hat{γ}\_{i,t,\pm h}$ are the realized co-variances at different leads and lags. Also R*i,t,1* = 0, and R*i,t,k* $≡$ Ri,t,k-1 + $\left(\sum\_{s=1}^{k-1}r\_{i,t,s}\right)^{2}+\left(\sum\_{s=0}^{k-2}r\_{i,t,m-s}\right)^{2}$. Note that TSRV is closely related to the Bartlett kernel used in constructing autocorrelation-consistent covariance matrix, e.g. [Newey and West (1987](#_ENREF_32)). As the Newey-West covariance matrix, TSRV corrects the effects of return autocorrelation. We also winsorize the daily TSRV at the 1st and 99th percentile to reduce the noise in extreme observations. With TSRV as the proxy for the variance of the efficient price, the information share of market *i* on day *t* is given by $IS\_{i,t}=\frac{TSRV\_{i,t}}{\sum\_{j=1}^{n}TSRV\_{j,t}}$.

A popular measure for price discovery in a non-overlapping setting is the weighted price contribution (WPC) proposed by [Barclay and Warner (1993](#_ENREF_3)) but named by [Cao, Ghysels and Hatheway (2000](#_ENREF_9)). If the return on day *t* in market *i* is r*i,t* and the return across all market is r*t*, the WPC for market *i* over the sample period is defined as:

|  |  |
| --- | --- |
| $WPC\_{i}= \sum\_{t=1}^{T}\frac{r\_{i,t}}{r\_{t}}\left(\frac{|r\_{t}|}{\sum\_{s=1}^{T}|r\_{s}|}\right)$  | (3) |

Under the assumption of return normality, [Wang and Yang (2014](#_ENREF_40)) examine the asymptotic properties of WPC. Let r*-i,t* be the total return in the other markets so that r*t*= ri*,t* + r-i,t. Define σ2 = var(r­*t*), $σ\_{i}^{2}$ = var(r­i,t), $σ\_{-i}^{2}$ = var(r­-i,t), and ρ = cor(ri,t, r-i,t). Wang and Yang (2014) show that when the mean return is close to zero, as in the case of daily or intraday returns, WPCi $\rightarrow \frac{σ\_{i}^{2}+ρσ\_{i}σ\_{-i}}{σ^{2}}$. Because WPC depends on the volatility in other markets through the return correlation *ρ*, it is not an appropriate measure for information flow. If *ρ* is close to zero, i.e. returns are independent, WPC is a reasonable proxy for information share. While recognizing the theoretical difference between IS and WPC, we estimate WPC as a robustness check for IS.

1. Global Information Distribution in the OTC gold market

***Data and Markets***

We use intraday gold spot trade and quote data (identified by Reuters identifier XAU=) from Thomson Reuters Tick History (TRTH). The data provided consists of market participants that meet Reuters' contributor criteria, which ensure that contributors are of sufficient credit quality and actively providing liquidity.[[7]](#footnote-7) Our data are intraday quotes from all contributors, including the LBMA members as well as other high quality institutions around the world. Our data differs from other studies of global gold trading in that we use OTC spot data across the 24-hour period whereas prior studies rely on London (e.g. [Lucey, Larkin and O’Connor (2014](#_ENREF_29))) or on closing quotes in different regions (e.g. [Laulajainen (1990](#_ENREF_25))).

We extract data from TRTH at 1-minute intervals from January 1, 1996 to December 31, 2012. This period is chosen as 1996 was the earliest available data and 2012 was the last full year of data available at the start of this study. Weekends and public holidays are removed due to thin trading. For each interval, the data include the number of trades as well as the last bid and ask quotes. The mid-point of the bid and ask quotes is used to construct TSRV. The number of trades and the return in each interval are used to calculate the imbalance between buy and sell orders.

To measure the global information distribution, we divide the 24-hour gold OTC market into four regional markets, i.e. *n* = 4 for each trading day. While it is natural to divide the world into Asia, Europe, and the United States based on their geography and time zones, we single out the overlapping trading hours between London and New York City as a separate market (London/New York). Table 1 reports the division of markets based on Greenwich Mean Time (GMT) with and without daylight saving time (DST). During non-DST, Asia covers 23 GMT to 6 GMT, Europe covers 7 GMT to 13 GMT, London/NYC covers 14 GMT to 15 GMT, and U.S. covers 16 GMT to 22 GMT. During DST, GMT shifts back by one hour relative to local time.

The two-hour London/New York market covers 2 to 4 pm London local time and 9 to 11 am New York local time. This is a period when financial markets in New York start trading. There is a wide range of financial products traded in New York which have value implications for gold. For example, the link between gold and crude oil is studied by [Reboredo (2013a](#_ENREF_35)) and the dependence between gold and exchange rates has been documented by [Pukthuanthong and Roll (2011](#_ENREF_34)) and [Reboredo (2013b](#_ENREF_36)). The period also covers the afternoon London gold fixing which produces an important global benchmark price ([Caminschi and Heaney (2014](#_ENREF_8))). We expect that the London/ New York market has greater information flow than London trading before New York opens and New York trading after London closes.

After separating the London/New York market, Europe covers OTC trading in Frankfurt, Zurich, and up to 2 pm in London; U.S. covers OTC trading after 11 am in New York as well as trading in Chicago and U.S. west coast. Trading of other financial products, e.g. index and commodity futures in Chicago, may have information spillover into OTC gold trading. While the separation across regional markets is somewhat arbitrary, the benefit of having non-overlapping markets is that we can clearly separate return innovations in each market.

[INSERT TABLES I AND II HERE]

Panel A of Table II reports the summary statistics of TSRV, our measure for information flow. The eight-hour Asian trading has the lowest average daily TSRV, even lower than the two-hour London/New York market. It has the highest volatility of TSRV relative to its mean. Using the normal distribution as a benchmark, Asian TSRV is less “well behaved” than other markets with higher skewness and kurtosis. TSRVs are similar in Europe and U.S.. London/New York has the highest per-hour TSRV.

The ratio of TSRV to the more conventional realized variance (RV) is reported in Panel B of Table II. Since TSRV removes microstructure noise from RV, the ratio represents information flow relative to the total price variation. A higher ratio implies a more efficient market. The ratio increased over the sample period across all markets, indicating improved market efficiency. Asia is the least efficient among the four, except in the late 1990s when the Tokyo Commodity Exchange was a major center for gold futures. In recent years, the London/New York market has the highest ratio, indicating greater information content in the observed price changes.

The characteristics of the OTC gold transactions are summarized in Panel C of Table II, as well as Figure 3a and 3b. During the sample period, Europe has the highest share of trading at 35.2%. Its share of OTC gold transactions had a strong increase from 15% in 2002 to 41% in 2008 (Figure 3a). Asia’s share of OTC transactions also had a strong increase from a low of 6% in 2001 to a high of 26% in 2010. The shares of London/New York and U.S. declined after 2001-2002, with a mild rebound for U.S. since 2008. Overall the OTC gold trading was relatively flat until a sharp increase in 2007-2008. The peak value in 2011 is over ten times of the trades in 2006. Figure 3b depicts the intraday trading pattern. In the earlier years (1996 – 2007), volume is low throughout the Asian hours up to 11 GMT. This change in 2008-2012 as volume rises towards the end of Asian trading hours and peaks before the 3pm London Gold Fixing. As shown in Figure 3a, volume surged in the 2008-2012 period. For 2008 – 2012, volume bounces back after 21 GMT, possibly due to increased early morning trading in New Zealand and Australia.

 [INSERT FIGURE 3A AND 3B HERE]

***Global Information Distribution***

Table III reports the average daily information shares of the four markets, Asia, Europe, London/New York, and U.S. For the full sample, the average information shares of Asia, Europe, London/New York and U.S. are 17%, 31%, 22% and 30% respectively. The information shares have relatively low time-series variations thus high *t*-statistics. These estimates indicate that geographically, the global distribution of trading is not the same as the global distribution of information. Even though Asia has 21.5% of the OTC trades (Table II Panel C), it has only 17% of global information. On the other hand, London/New York has 14.6% of the OTC trades but 22% of global information. One unit traded in different locations may have different information content. Furthermore, the estimates do not support the claim by LBMA that “the global bullion market is based on expertise and liquidity in London”. Ignoring the contributions of other cities in Europe and U.S., the London morning fixing does not significantly boost the information share of London morning trading. If the 22% information share for London/New York is split equally between the two cities[[8]](#footnote-8), they each have around 41% information share. The finding is consistent with that of Lucey et al. (2013).

On a per-hour basis, the information shares are 2.1%, 4.4%, 11%, and 4.3% for Asia, Europe, London/New York, and U.S. respectively. Therefore the per-hour rate of information flow in Asia is 2.1% of the total daily information, and the per-hour rate of information flow in London/New York is 11% of the total daily information. While the notion of high information intensity during the London/New York overlapping hours is not new, the quantified level of information intensity is still striking: the rate of information flow during the London/New York overlapping hours is two and half times of the rate of information flows before (Europe) and after (U.S.), and over five times of the rate of information flow in Asia. The finding supports the notion that the concurrent trading of multiple assets in multiple markets, as happens during the London/ New York period, significantly enhances the market’s information production and price discovery.

The historical evolution of global information distribution is depicted in Figure 4. Despite Asia’s rising share of OTC trades from around 10% in the late 1990s to the peak of 26% in 2010 (Figure 3a), its information share has experienced a significant decline from around 20% in the late 1990s to around 15% in 2009-2012. On the other hand, the information share of the London/New York market increased from 18% in the late 1990s to around 23% in 2009-2012. The time trend for the information shares of Europe and U.S. is relatively flat. The impact of gold ETFs in U.S. appears to be local: information comes out of ETF trading instead of futures trading ([Ivanov (2011](#_ENREF_23))). It has not shifted the global information distribution in favor of U.S. For Asia, the strong demand for physical gold and the sharp rise in spot and derivatives trading have not led to greater capacity for price discovery. The low volatility (Table II) and low information share indicate that Asia remains largely a price taker, trading gold at prices set in London and New York.

These findings are somewhat surprising given the trends discussed in section II. The continued information dominance of Europe and U.S., and increasing importance of London/New York, may be explained by several factors. First, gold is denominated in USD and London and New York are the global centers for currency trading. [Wang and Yang (2011](#_ENREF_39)) show that the overlapping trading hours between London and New York have become more important for currency pricing. The link between gold and USD has been widely documented, e.g. [Reboredo (2013a](#_ENREF_35)) and the references therein. Second, gold is widely used as a safe haven asset and for portfolio diversification. The size of the financial assets in Europe and U.S. implies a significant demand for gold for hedging and diversification, especially during and after the global financial crisis in 2007-09. Third, the institutional capacity for information collection and processing is much stronger in Europe and U.S. than it is in Asia. The London Bullion Market Association embodies significant institutional knowledge and expertise on the global gold production, demand and pricing. Fourth, the gold market may have experienced the same consolidation as in the OTC foreign exchange markets, with the top five FX dealing banks accounting for 80% of interbank trading ([Wallace (2014](#_ENREF_38))). The concentration of trading to a few mega banks in London and New York and their increased client base are likely to concentrate pricing information to these mega banks, thus increasing the information share of London/New York at the expense of new markets in Asia.

The estimated WPCs are reported in Table IV. The average WPCs are 21%, 30%, 20%, and 29% for Asia, Europe, London/New York, and U.S. respectively. The estimated WPCs are broadly similar to the estimated information shares (17%, 31%, 22%, and 30%), with the largest difference with the estimated information shares is at 4% for Asia. Even though the standard deviations of the annual WPCs are much higher than those of the information shares, the average WPC for each market is still significant at 1%. The WPCs of different markets show strong convergence in the late 1990s. Asia and U.S. had a mild decline up to the financial crisis in 2008, with Europe and London/New York having a mild rising trend over the same period. Asia’s WPC had a significant rebound since 2008 at the expense of London/New York and Europe.

[INSERT TABLE III HERE]

[INSERT FIGURE 4 HERE]

1. Volatility Spillovers and Private Information Flows

In this section we estimate cross-market volatility spillovers and the flows of private information in each market. It is well known that volatility is highly persistent and has long memories. Numerous studies have examined cross-market volatility spillovers, dating back to [Engle, Ito and Lin (1990](#_ENREF_17)). The spillovers are interpreted as information flowing from one market to the next. [Lucey, Larkin and O’Connor (2014](#_ENREF_29)) show significant return and volatility spillovers across London, New York, and Tokyo, with Shanghai being relatively isolated. [Laulajainen (1990](#_ENREF_25)) find gold price dependency in the market immediately preceding it, e.g. the New York Commodity Exchange gold price is dependent on the price in the London gold market.

***Measuring Volatility Spillovers***

In this study, volatility spillover is captured though a dynamic model for each market’s TSRV. To simplify the notations, we denote TSRV*i,t* by V*i,t* for *i* = A (Asia), E (Europe), L (London /New York) and U (U.S.). TSRV measures variations in the efficient price, which are serially independent. Daily TSRV is given by V*t* = $\sum\_{i=A}^{U}V\_{i,t}$. Because variance has long memory, lagged variance beyond one day is represented by variance on lagged 2 to 5 days $V\_{t-1,W}=\sum\_{k=2}^{5}V\_{t-k}$ and variance on lagged 6 to 22 days $V\_{t-1, M}=\sum\_{k=6}^{22}V\_{t-k}$. The dynamic model for TSRV is:

|  |  |
| --- | --- |
| lnVi*,t* = α*i* + $β\_{i,A}lnV\_{A,t-1}+β\_{i,E}lnV\_{E,t-1}+β\_{i,L}lnV\_{L,t-1}+β\_{i,U}lnV\_{U,t-1}$+βWlnV*t-1,W*+βMlnV*t-1,M* + ε*i,t*, *i* = A, E, L and U.  | (4) |

This specification of volatility dynamics is similar to the heterogeneous autoregressive (HAR) model of [Corsi (2009](#_ENREF_12)) which has been widely adopted in volatility studies to capture the long memory in volatility ([Andersen, Bollerslev and Diebold (2007](#_ENREF_1)), [Andersen, Bollerslev and Huang (2006](#_ENREF_2)), [Bollerslev *et al.* (2009](#_ENREF_7)), [Corsi *et al.* (2008](#_ENREF_13)), [Forsberg and Ghysels (2007](#_ENREF_18)) and [Maheu and McCurdy (2011](#_ENREF_31))). The log transformation allows the dependent variable to be positive or negative. The coefficients βW and βM captures the long-run dependence of volatility. The short-run dependence, typically represented by the one-day lagged volatility lnVi,t-1, is represented here by the lagged volatilities in four different markets. The coefficient β*i,j* (*j* = A, E, L and U) measures the short-run volatility spillover from market *j* to market *i*. Note that the *t*-1 lag represents the market immediately prior to market *i*, which may be on the same day as market *i*. For example, when *i* = Asia, the first market to trade on day *t*, lnVj,t-1 (j = A, E, L and U) are all from the previous day *t*-1. When *i* = U.S., the last market to trade on day *t*, lnVj,t-1 (j = A, E, and L) are actually from the same day *t* with only the lagged U.S. volatility from the previous day. When *i* = Europe, lnVA,t-1 the log variance of Asia is from the same day (before Europe opens) but lnVE,t-1, lnVL,t-1, and lnVU,t-1 are all from the previous day. This model is used to measure short-run volatility spillover while taking into account the long memory in volatility. The error term is assumed to be normally distributed and the model is estimated via OLS as in previous studies. Statistical inferences are based on the Newey-West robust standard errors. Figure 5 shows that when estimated using OTC gold TSRV, the model removes most but not all volatility dependence.

[INSERT FIGURE 5 HERE]

***Measuring Private Information Flows***

We amend the above model with two order flow variables to capture the link between trading and volatility: the number of trades T*i,t* and the order imbalance Z*i,t* in market *i* on day *t*. Both have been shown to be important determinants of daily volatility, e.g. [Chan and Fong (2000](#_ENREF_10)). As demonstrated by Berger et al (2009) for the foreign exchange market, order flows play a significant role in determining volatility long memory. Therefore adding these variables should help remove the remaining autocorrelation from the residuals. More importantly order flow is the main channel through which investors’ private information is incorporated into the observed prices (see studies cited in footnote 4). We use the impact of unexpected order flows on TSRV to measure the amount of private information present in the order flow variables. Following [Bessembinder and Seguin (1993](#_ENREF_6)), both T*i,t* and Z*i,t* are modeled as an AR(5) process with the fitted AR(5) as the expected value and the residuals as the surprise component. The expected component is assumed to be public knowledge. Any private information should impact volatility through the surprise component. Let $T\_{i,t}^{e}$ and $Z\_{i,t}^{e}$ be the expected components and $T\_{i,t}^{u}$ and $Z\_{i,t}^{u}$ be the unexpected components. The amended model for TSRV is given by:

lnVi*,t* = αi + $β\_{i,A}lnV\_{A,t-1}+β\_{i,E}lnV\_{E,t-1}+β\_{i,L}lnV\_{L,t-1}+β\_{i,U}lnV\_{U,t-1}$ + βi,WlnVt-1,W + βi,MlnVt-1,M

+$ β\_{i,T}^{e}T\_{i,t}^{e} $+$ β\_{i,T}^{u}T\_{i,t}^{u }$+$ β\_{i,Z}^{e}Z\_{i,t}^{e} $+$ β\_{i,Z}^{u}Z\_{i,t}^{u} $+ εi,t, *i* = A, E, L and U. (5)

With the exception of $T\_{i,t}^{u}$ and $Z\_{i,t}^{u}$, all other explanatory variables are observable before market *i* opens, including $T\_{i,t}^{e}$ and $Z\_{i,t}^{e}$ which are based on past trading. The impact of new information in market *i* on day *t* is embedded in $T\_{i,t}^{u}$ and $Z\_{i,t}^{u}$. Theoretically public information leads to an immediate quote change by the posting dealer without the need for trading, e.g. [Kyle (1985](#_ENREF_24)). Private information motivates investors to trade for profits, revealing his/ her private information in the process. Therefore the impact of the unexpected order flows $T\_{i,t}^{u}$ and $Z\_{i,t}^{u}$ captures the flow of private information or beliefs. Empirically however, news announcements do generate abnormal trading volume. Part of the news-driven volume is portfolio adjustments which cause short-term price changes due to liquidity friction. These price changes tend to be serially correlated as they are driven by the same news or event. Another part is due to investors searching for the new equilibrium price. Studies have shown that in most cases, price converges to the new equilibrium within a few minutes ([Patell and Wolfson (1984](#_ENREF_33)), [Chordia, Roll and Subrahmanyam (2005](#_ENREF_11))). Therefore we regard the impact of $T\_{i,t}^{u}$ and $Z\_{i,t}^{u}$ is mostly due to private information.

The order imbalance Z*i,t* is defined as the number of buyer-initiated orders minus the number of seller-initiated orders in market *i* on day *t*. Following [Easley *et al.* (2008](#_ENREF_15)), the number of buyer initiated trades in the *j*th 5-minute period in market *i* on day *t* is $T\_{j,i,t}^{B}=T\_{j,i,t}Z\left(\frac{r\_{j,i,t}}{σ\_{t}}\right)$; the number of seller initiated trades is $T\_{j,i,t}^{S}=T\_{j,i,t}\left[1-Z\left(\frac{r\_{j,i,t}}{σ\_{t}}\right)\right]$, where $T\_{j,i,t}$ is the number of trades in the *j*th 5-minute period in market *i* on day t, rj,i,t is the return, σt is the standard deviation of rj,i,t across all four markets in day *t*, and $Z\left(⋅\right)$ is the normal cumulative density function. Hence, order imbalance is $Z\_{i,t}= \sum\_{j=1}^{M\_{i}}(T\_{j,i,t}^{B}- T\_{j,i,t}^{S})$ with Mi being the number of 5-minute periods in market *i*.

***Empirical Findings***

Table V reports the estimated coefficients of equation (5) for Asia, Europe, London/New York and U.S. respectively. To explore any time variation over the sample period, we estimate the model for three sub-periods, 1996-1999, 2000-2007, 2008-2012, as well as the full sample. The long memory variables, i.e. the weekly and monthly lags, are all highly significant in all sub-periods and the full sample. The self- and cross-market dependence in volatility reveals some interesting features in the global OTC gold market.

* Volatility in each market has a significant dependence on its own volatility 24 hours ago. This self-dependence is unaffected by information flow captured by volatilities in previous markets in the 24-hour cycle or by the contemporaneous order flows in the local market. It may reflect long-lived private information (more than 24 hours) held by local investors, e.g. Holden and Subrahmanyam (1992) and Foster and Viswanathan (1994). However this self-dependence is strongest in Asia which has limited capacity for information collection and processing, and is weakest in London/New York (still statistically highly significant) which are the global hubs for financial information. Therefore long-lived private information is unlikely to be the key factor for volatility self-dependence. We believe that under the structure of four sequential markets, volatility self-dependence is likely to come from local market characteristics such as the mix of individual and institutional investors, their size of financial endowments and risk tolerance, etc. For example, Asia is dominated by individual investors speculating on gold price which London and New York are dominated by institutions using gold to hedge volatility in other assets.
* With the exception of Asia, other markets have the greatest volatility spillover from the market immediately precedes its trading. In Panel B of Table V, Europe has greater dependence on Asia than on its own lag.[[9]](#footnote-9) Similarly London/New York has the greatest dependence on lagged Europe; and U.S. has the greatest dependence on lagged London/New York. For these markets, short-run volatility persistence is mostly driven by information spillover from the previous market, with a smaller portion driven by their own lags 24 hours ago.
* The effects of order flows vary across markets and time periods. The expected components either have no effect or smaller effect than the unexpected components. This is consistent with market efficiency as past information (upon which expectation is formed) is largely reflected in market prices. The unexpected number of trades is always highly significant, as documented in several previous studies. The unexpected order imbalance is highly significant in recent years and for the whole sample. The negative coefficients indicate that more buyer-initiated trades are associated with lower volatility, and vice versa for seller-initiated trades.

 [INSERT TABLE V HERE]

In Table VI, we report the estimated private information flow in each market. From Table V, private information flow in market *i* on day *t* is calculated as Privi,t = exp($\hat{β}\_{i,T}^{u}T\_{i,t}^{u }$+$ \hat{β}\_{i,Z}^{u}Z\_{i,t}^{u}$), *i* = A, E, L and U. Since Privi,t are the estimated variances of changes of the efficient price due to private information, the total private information on day *t* is given by Privt = $\sum\_{i=A}^{U}Priv\_{i,t}$. The share of private information of market *i* on day *t* is Privi,t/Privt.

Table VI reports the estimated private information flows, private information shares, and per-hour private information shares across markets and over time.

* Panel A shows that the order flow-based private information flows are remarkably stable, especially during 1996 – 2007. This is different from the volatility-based overall information shares depicted in Figure 3a. It is consistent with the relatively flat total OTC volume from 1996 to 2007 period. The surge in trading in 2008 – 2012 is associated with a significant drop in Asia’s share of private information and increases in Europe and U.S. The severe financial crisis in 2008 – 2009 had its origin in the U.S. market. It was followed by crises in southern European countries in 2010 – 2011. These crises pushed the demand for gold as the safe-haven asset and greater information-motivated trading in Europe and U.S.
* Panel B shows that compared to the overall information distribution in Table III, London/New York has a slightly higher share of private information. Again this is not surprising since London and New York are the global hubs for the trading of gold and gold-relevant assets. The distribution of private information across Asia, Europe, and U.S. is flatter relative to the distribution of the overall information. Asia’s share of private information is 21.6% for the full sample, significantly higher than its 17% share of the overall information. Europe and U.S. have 27.6% and 26.8% shares of private information respectively, lower than their shares of general information. The flatter distribution of private information may reflect the presence of the same global dealers, mostly investment banks, in different markets. In addition, gold is widely held as an investment asset in Asia while it is widely used by institutional investors in Europe and U.S. as a hedge against volatilities in other assets.
* The per-hour private information share (Panel C) of Asia is still very low relative to other markets and has decreased over time. For the full sample, it is about 70% of the per-hour shares of Europe and U.S. and only 23% of the per-hour share of London/New York. Gold trading in Asia is dominated by individual speculators and it is dominated in other markets by large financial institutions. The institutional capacity for information collection and processing is much stronger in Europe and U.S. than it is in Asia.

 [INSERT TABLE VI HERE]

1. Conclusion

Asia has been the largest producer and consumer of gold for many years. Demand for gold in China, as a portion of the total global demand, has a strong positive correlation with gold price. Financial trading of gold-related spot and futures contracts has surged in Asia, particularly Shanghai. These observations led us to the hypothesis that Asia is playing a greater role in the global gold market and trading in Asia has greater information content for the pricing of gold.

Using the two-scale estimator of realized variance as a proxy for information flow, we reject the hypothesis as Asia’s information share has increased in proportion to its demand and trade share during 1996 – 2012. We find the eight-hour Asian trading only contributes on average 17% towards daily information flows, while the two-hour London/New York market contributes 22%. On a per-hour basis, the rate of information flow in London/New York is over five times of the rate of information flow in Asia. Contrary to its rising shares in trading volume, Asia’s information share has steadily declined from around 20% in the late 1990s to around 15% in 2009-2012. While gold is produced and consumed in Asia, its pricing is mostly determined in Europe and the U.S..

When analyzing volatility dynamics across markets, we find evidence of self-dependence where volatility in one market has a significant autocorrelation with its own lag 24 hours ago. This self-dependence is strongest in Asia but also present in other markets. We argue that it is unlikely to come from long-lived private information (more than 24 hours), but rather from local market characteristics such as individual versus institutional investors, their size of financial endowments and risk tolerance, etc.

Finally we show that Asia's private information flow remains low at 2.7% per hour compared with 4% for Europe and U.S. and 12% for London/ New York. This is consistent with investors in Asia having limited capacity for information collection and processing relative to their counterparts in Europe and U.S.

To our best knowledge, this study provides the first empirical evidence on information distribution across the global gold markets and how such distribution has shifted over a 17-year period from 1996 to 2012. The evidence we present should raise concerns to officials and policymakers on gold market development in Asia. Despite being the largest producer and consumer of gold and the rising trading volume in gold-related financial contracts, Asia’s contribution to the pricing of gold, i.e. its price discovery process, has steadily declined. Since the Asian financial crisis in the late 1990s, governments in Asia have made a strong effort to develop a regional bond market to prevent the flow of local savings to U.S. Treasury bonds as a safe-haven asset. Gold is another safe-haven asset whose prices and volatility have a significant impact on portfolio performance and investor welfare in Asia. Officials and policymakers in Asia should not feel contented with its rising share of trading volume, but rather make a strong commitment to reverse its declining information share by enhancing the local market infrastructure (e.g. local clearing and settlement) and building research infrastructure and capacity.

The rising information share of the 2-hour London/New York market together with its declining share of trading volume should also raise concerns to global investors and market regulators. The gold market seems to follow the same trend of consolidation in the foreign exchange markets where a handful of dealers accounts for 80% of interbank trading. Such concentration reduces the opaque nature of the OTC market and enhances information flows to the large dealers. It should improve their pricing accuracy and increase the information content of the posted prices. However the market may become more fragile if one or two of the handful dealers withdraw from supplying liquidity. It may also become more susceptible to price manipulation as occurred in the foreign exchange markets.

This is the first attempt to measure the global information distribution in the gold market. Future research should explore factors affecting the information share of a particular market, e.g. market infrastructure, liquidity, investor characteristics, and possible cross-product information spillovers. The methodology of this study can be applied to any product traded in non-overlapping markets. New methodologies are needed to measure information shares of partially overlapping markets while taking into account the common information flow during the overlapping period.

**References**

Andersen, T. G., T. Bollerslev, and F. X. Diebold, 2007, Roughing it up: Including jump components in the measurement, modeling, and forecasting of return volatility, *Review of Economics and Statistics* 89, 701-720.

Andersen, T. G., T. Bollerslev, and X. Huang, 2006, A semiparametric framework for modelling and forecasting jumps and volatility in speculative prices, *Working Paper, Duke University*.

Barclay, M. J., and J. B. Warner, 1993, Stealth trading and volatility : Which trades move prices?, *Journal of Financial Economics* 34, 281-305.

Barndorff-Nielsen, O. E., P. R. Hansen, A. Lunde, and N. Shephard, 2008, Designing realized kernels to measure the ex post variation of equity prices in the presence of noise, *Econometrica* 76, 1481-1536.

Baur, D. G., 2013, Exchange-traded funds on gold-a free lunch?, *Working Paper, Kuehne Logistics University*

Bessembinder, H., and P. J. Seguin, 1993, Price volatility, trading volume, and market depth: Evidence from futures markets, *Journal of Financial and Quantitative Analysis* 28, 21-39.

Bollerslev, T., U. Kretschmer, C. Pigorsch, and G. Tauchen, 2009, A discrete-time model for daily s&p 500 returns and realized variations: Jumps and leverage effects, *Journal of Econometrics* 150, 151-166.

Caminschi, A., and R. Heaney, 2014, Fixing a leaky fixing: Short-term market reactions to the london pm gold price fixing, *Journal of Futures Markets* 34, 1003-1039.

Cao, C., E. Ghysels, and F. Hatheway, 2000, Price discovery without trading: Evidence from the nasdaq preopening, *Journal of Finance* 55, 1339-1365.

Chan, K., and W.-M. Fong, 2000, Trade size, order imbalance, and the volatility–volume relation, *Journal of Financial Economics* 57, 247-273.

Chordia, T., R. Roll, and A. Subrahmanyam, 2005, Evidence on the speed of convergence to market efficiency, *Journal of Financial Economics* 76, 271-292.

Corsi, F., 2009, A simple approximate long-memory model of realized volatility, *Journal of Financial Econometrics* 7, 174-196.

Corsi, F., S. Mittnik, C. Pigorsch, and U. Pigorsch, 2008, The volatility of realized volatility, *Econometric Reviews* 27, 46-78.

Easley, D., M. M. L. de Prado, and M. O'Hara, 2012, Flow toxicity and liquidity in a high-frequency world, *Review of Financial Studies* 25, 1457-1493.

Easley, D., R. F. Engle, M. O'Hara, and L. Wu, 2008, Time-varying arrival rates of informed and uninformed trades, *Journal of Financial Econometrics* 6, 171-207.

Easley, D., N. M. Kiefer, and M. O'Hara, 1997, One day in the life of a very common stock, *Review of Financial Studies* 10, 805-835.

Engle, R. F., T. Ito, and W.-L. Lin, 1990, Meteor showers or heat waves? Heteroskedastic intra-daily volatility in the foreign exchange market, *Econometrica* 58, 525-542.

Forsberg, L., and E. Ghysels, 2007, Why do absolute returns predict volatility so well?, *Journal of Financial Econometrics* 5, 31-67.

Fuangkasem, R., P. Chunhachinda, and S. Nathaphan, 2012, Information transmission among world major gold futures markets: Evidence from high frequency synchronous trading data, *Working Paper, Thammasat University.* .

Harris, F. H., T. M. McInish, and R. Wood, 2002, Security price adjustment across exchanges: An investigation of common factor components for dow stocks, *Journal of Financial Markets* 5, 277-308.

Hasbrouck, J., 1995, One security, many markets: Determining the contributions to price discovery, *Journal of Finance* 50, 1175-1199.

Huang, R., and H. Stoll, 1997, The components of the bid-ask spread: A general approach, *Review of Financial Studies* 10, 995-1034.

Ivanov, S. I., 2011, The influence of etfs on the price discovery of gold, silver and oil, *Journal of Economics and Finance* 37, 453-462.

Kyle, A. S., 1985, Continuous auctions and insider trading, *Econometrica* 53, 1315-1336.

Laulajainen, R., 1990, Gold price round the clock: Technical and fundamental issues, *Resources Policy* 16, 143-152.

Lehmann, B. N., 2002, Some desiderata for the measurement of price discovery across markets, *Journal of Financial Markets* 5, 259-276.

Lin, J., G. Sanger, and G. Booth, 1995, Trade size and components of the bid-ask spread, *Review of Financial Studies* 8, 1153-1183.

Lucey, B. M., C. Larkin, and F. A. O'Connor, 2013, London or new york: Where and when does the gold price originate?, *Applied Economics Letters* 20, 813-817.

Lucey, B. M., C. Larkin, and F. O’Connor, 2014, Gold markets around the world–who spills over what, to whom, when?, *Applied Economics Letters* 21, 887-892.

Madhavan, A., M. Richardson, and M. Roomans, 1997, Why do security prices change? A transaction-level analysis of NYSE stocks, *Review of Financial Studies* 10, 1035-1064.

Maheu, J. M., and T. H. McCurdy, 2011, Do high-frequency measures of volatility improve forecasts of return distributions?, *Journal of Econometrics* 160, 69-76.

Newey, W. K., and K. D. West, 1987, Hypothesis testing with efficient method of moments estimation, *International Economic Review* 28, 777-787.

Patell, J. M., and M. A. Wolfson, 1984, The intraday speed of adjustment of stock prices to earnings and dividend announcements, *Journal of Financial Economics* 13, 223-252.

Pukthuanthong, K., and R. Roll, 2011, Gold and the dollar (and the euro, pound, and yen), *Journal of Banking & Finance* 35, 2070-2083.

Reboredo, J. C., 2013a, Is gold a hedge or safe haven against oil price movements?, *Resources Policy* 38, 130-137.

Reboredo, J. C., 2013b, Is gold a safe haven or a hedge for the us dollar? Implications for risk management, *Journal of Banking & Finance* 37, 2665-2676.

Thomson Reuters, 2014, Gfms gold survey 2014.

Wallace, C., 2014, Daily london currency pricing may need a tweak, Institutional Investor.

Wang, J., and M. Yang, 2011, Housewives of tokyo versus the gnomes of zurich: Measuring price discovery in sequential markets, *Journal of Financial Markets* 14, 82-108.

Wang, J., and M. Yang, 2014, How well does the weighted price contribution measure price discovery?, *Working Paper, University of Technology, Sydney*.

Zhang, D., 2005, Price discovery in gold markets: China and the us, *Working Paper, Stockholm University School of Business*.

Zhang, L., P. A. Mykland, and Y. Aït-Sahalia, 2005, A tale of two time scales, *Journal of the American Statistical Association* 100, 1394-1411.

**Figure 1a: Gold ETF Trading Volume**

This graph reports the total U.S. dollar trading volume per year in gold ETFs globally from 2002 to 2012. Data is from Bloomberg.

**Figure 1b: Gold ETF and Gold Price**

This is Figure 5 from [Baur (2013](#_ENREF_5)) showing the number of gold ETFs and the gold price.

****

**Figure 2a: Global Demand for Gold**

This graph reports total world gold investment and jewellery demand, emphasizing the top three countries with the largest demand for the period 1997 to 2012. Data is from quartlerly Gold Demand Reports by the World Gold Council.

**Figure 2b: Chinese Shares of Gold Demand and Gold Price**

This graph shows the relationship between the gold price and China’s proportion of gold demand. Gold price data is from Bloomberg, investment and jewelry demand is from the World Gold Council.

**Figure 3a: Number of Gold Transactions over Time**

This graph shows the number of trades and the proportion of trading activity allocated to each sequential market for the period 1996 to 2012. Data is from the Thomson Reuters Tick History (TRTH) database.

**Figure 3b: Per-hour Number of Transactions over a 24-hour Period**

This graph shows the daily average number of trades per hour across a 24-hour period broken into sub periods from 1996 to 2012. Data is from the Thomson Reuters Tick History (TRTH) database.

Asia

U.S.

Europe

Asia

**Figure 4: Information Distribution**

This graph shows the average daily information shares per year from 1996 to 2012 of Asia, Europe, London/ New York and U.S. in the gold over-the-counter market, based on each market’s daily two-scale realized variance. Data is from the Thomson Reuters Tick History (TRTH) database.

**Figure 5: TSRV and HAR Residual Autocorrelations**

Table I

Regional Time Zones including Daylight Saving

This table divides a 24-hour trading day into the four markets: “Asia”, “Europe”, "London/New York" and “U.S.” adjusted for European Daylight Savings Time (DST). The indicated market hours are inclusive, e.g. Europe starts at 7:00:00 GMT and ends at 13:59:59 GMT during non-DST periods. During European DST, London local time is one hour ahead of GMT, i.e. GMT+1.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Period  | Asia | Europe | London/New York | U.S. |
| No Europe DST | 23:00 to 6:00 | 7:00 to 13:00 | 14:00 to 15:00 | 16:00 to 22:00 |
| Europe DST | 22:00 to 5:00 | 6:00 to 12:00 | 13:00 to 14:00 | 15:00 to 21:00 |

**Table II**

**Summary Statistics**

This table reports summary statistic measures for daily two-scale realized variance (TSRV) in Panel A, number of trades Panel B and the daily average ratios of two-scaled realised variance of realised variance broken up into Asia, Europe, London/New York and U.S. markets in the over-the-counter gold market from 1996 to 2012.

|  | Asia | Europe | London/New York | U.S. |
| --- | --- | --- | --- | --- |
| **Panel A. TSRV\*10000** |  |  |  |  |
| Mean | 18.53 | 33.37 | 24.64 | 34.28 |
| Standard Deviation | 29.93 | 39.15 | 31.89 | 40.53 |
| Skewness | 4.64 | 3.01 | 3.55 | 2.87 |
| Kurtosis | 25.77 | 10.49 | 16.05 | 9.40 |
|  |  |  |  |  |

**Panel B. Daily Average TSRV to RV Ratios**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| 1996-2000 | 0.81 | 0.85 | 0.74 | 0.78 |
| 2001-2007 | 0.87 | 0.91 | 0.88 | 0.89 |
| 2008-2012 | 0.93 | 0.94 | 0.96 | 0.93 |
|  |  |  |  |  |

**Panel B. Number of Trades**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Mean | 764 | 1249 | 520 | 1017 |
| Percentage Share | 21.5% | 35.2% | 14.6% | 28.6% |
| Standard Deviation | 1130 | 1798 | 578 | 1234 |
| Skewness | 1.63 | 1.46 | 2.11 | 1.55 |
| Kurtosis | 2.23 | 1.26 | 6.86 | 1.67 |

Table III

Average Daily Information Shares

This table reports the average daily information shares for Asia, Europe, London/New York and U.S. in the gold OTC market. The *t-*statistics are in the square brackets with asterisks \*\*\*, \*\*, and \* indicating significant at 1%, 5%, and 10% respectively. The t-statistics for each year and the full sample are based on the standard deviation of daily information shares. The *t*-statistics for the average per-hour information share are based on the standard deviations of the annual information shares divided by the square root of the number of hours in each market.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Asia |  | Europe |  | London/New York | U.S. |  |
| Full Sample | 0.17 | \*\*\* | 0.31 | \*\*\* | 0.22 | \*\*\* | 0.3 | \*\*\* |
|  | [86.31] |  | [157.8] |  | [125.43] |  | [134.48] |  |
| 1996 | 0.19 | \*\*\* | 0.28 | \*\*\* | 0.18 | \*\*\* | 0.35 | \*\*\* |
|  | [19.55] |  | [33.24] |  | [26.1] |  | [35] |  |
| 1997 | 0.18 | \*\*\* | 0.28 | \*\*\* | 0.19 | \*\*\* | 0.36 | \*\*\* |
|  | [17.85] |  | [31.64] |  | [26.42] |  | [33.41] |  |
| 1998 | 0.22 | \*\*\* | 0.3 | \*\*\* | 0.17 | \*\*\* | 0.31 | \*\*\* |
|  | [22.88] |  | [36.21] |  | [25.76] |  | [32.32] |  |
| 1999 | 0.22 | \*\*\* | 0.3 | \*\*\* | 0.18 | \*\*\* | 0.3 | \*\*\* |
|  | [24.96] |  | [33.55] |  | [24.8] |  | [33.57] |  |
| 2000 | 0.18 | \*\*\* | 0.3 | \*\*\* | 0.21 | \*\*\* | 0.31 | \*\*\* |
|  | [22.07] |  | [35.99] |  | [28.81] |  | [33.76] |  |
| 2001 | 0.19 | \*\*\* | 0.3 | \*\*\* | 0.21 | \*\*\* | 0.3 | \*\*\* |
|  | [19.24] |  | [35.9] |  | [28.55] |  | [28.49] |  |
| 2002 | 0.18 | \*\*\* | 0.29 | \*\*\* | 0.21 | \*\*\* | 0.32 | \*\*\* |
|  | [19.47] |  | [33.88] |  | [28.98] |  | [27.1] |  |
| 2003 | 0.17 | \*\*\* | 0.29 | \*\*\* | 0.24 | \*\*\* | 0.29 | \*\*\* |
|  | [18.38] |  | [39.11] |  | [30.92] |  | [34.58] |  |
| 2004 | 0.16 | \*\*\* | 0.37 | \*\*\* | 0.22 | \*\*\* | 0.25 | \*\*\* |
|  | [19.16] |  | [40.05] |  | [30.34] |  | [32.91] |  |
| 2005 | 0.17 | \*\*\* | 0.35 | \*\*\* | 0.22 | \*\*\* | 0.26 | \*\*\* |
|  | [21.53] |  | [44.24] |  | [32.3] |  | [32.98] |  |
| 2006 | 0.18 | \*\*\* | 0.27 | \*\*\* | 0.26 | \*\*\* | 0.3 | \*\*\* |
|  | [22.28] |  | [48] |  | [38.31] |  | [40.33] |  |
| 2007 | 0.15 | \*\*\* | 0.3 | \*\*\* | 0.24 | \*\*\* | 0.31 | \*\*\* |
|  | [21.41] |  | [44.08] |  | [34.85] |  | [37.75] |  |
| 2008 | 0.15 | \*\*\* | 0.34 | \*\*\* | 0.23 | \*\*\* | 0.28 | \*\*\* |
|  | [23.35] |  | [49.77] |  | [38.31] |  | [38.16] |  |
| 2009 | 0.14 | \*\*\* | 0.35 | \*\*\* | 0.23 | \*\*\* | 0.28 | \*\*\* |
|  | [23.39] |  | [46.92] |  | [36.36] |  | [38.19] |  |
| 2010 | 0.15 | \*\*\* | 0.31 | \*\*\* | 0.24 | \*\*\* | 0.3 | \*\*\* |
|  | [26.76] |  | [42.85] |  | [33.74] |  | [34.94] |  |
| 2011 | 0.16 | \*\*\* | 0.31 | \*\*\* | 0.21 | \*\*\* | 0.31 | \*\*\* |
|  | [25.44] |  | [42.03] |  | [34.48] |  | [35.31] |  |
| 2012 | 0.14 | \*\*\* | 0.35 | \*\*\* | 0.23 | \*\*\* | 0.27 | \*\*\* |
|  | [25.9] |  | [41.01] |  | [32.53] |  | [27.75] |  |
| Average | 0.17 |  | 0.31 |  | 0.22 |  | 0.30 |  |
| St Dev | 0.024 |  | 0.030 |  | 0.025 |  | 0.028 |  |
| Per Hour IS | 0.021 |  | 0.044 |  | 0.11 |  | 0.043 |  |
| *t*-statistic | [2.50] |  | [3.91] |  | [6.22] |  | [4.05] |  |

Table IV

**Weighted Price Contributions**

The *t*-statistics for the average per-hour information share are based on the time-series standard deviations divided by the square root of the number of hours in each market.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **year** | **Asia** | **Euro** | **London/New York** | **US** |
| 1996 | 0.051 | 0.435 | 0.036 | 0.479 |
| 1997 | 0.197 | 0.298 | 0.119 | 0.387 |
| 1998 | 0.229 | 0.277 | 0.187 | 0.307 |
| 1999 | 0.320 | 0.263 | 0.188 | 0.229 |
| 2000 | 0.192 | 0.240 | 0.175 | 0.393 |
| 2001 | 0.219 | 0.317 | 0.193 | 0.271 |
| 2002 | 0.146 | 0.291 | 0.173 | 0.389 |
| 2003 | 0.176 | 0.248 | 0.262 | 0.313 |
| 2004 | 0.203 | 0.329 | 0.268 | 0.199 |
| 2005 | 0.242 | 0.306 | 0.260 | 0.191 |
| 2006 | 0.211 | 0.290 | 0.213 | 0.286 |
| 2007 | 0.223 | 0.341 | 0.234 | 0.202 |
| 2008 | 0.126 | 0.319 | 0.279 | 0.276 |
| 2009 | 0.177 | 0.337 | 0.212 | 0.274 |
| 2010 | 0.205 | 0.273 | 0.252 | 0.270 |
| 2011 | 0.307 | 0.257 | 0.160 | 0.276 |
| 2012 | 0.267 | 0.327 | 0.171 | 0.235 |
| Average | 0.205 | 0.303 | 0.199 | 0.293 |
| St Dev | 0.064 | 0.046 | 0.061 | 0.079 |
| Per-hour | 0.026 | 0.043 | 0.099 | 0.042 |
| *t*-statistic | 1.15 | 2.47 | 2.30 | 1.41 |

Table V

Two-scale Realized Variance Dynamics and Determinants

This table reports coefficient estimates of equation 5 for Asia (Panel A), Europe (Panel B), London/New York (Panel C) and U.S. (Panel D). The *t-*statistics are in the square brackets with asterisks \*\*\*, \*\*, and \* indicating significant at 1%, 5%, and 10% respectively.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Panel A. Asia** |  |  |  |  |
| Variable | 1996 to 1999 | 2000 to 2007 | 2008 to 2012 | Full Sample |
| Intercept | -3.56\*\*\* | -2.51\*\*\* | -2.32\*\*\* | -2.07\*\*\* |
|   | [-6.25] | [-9.11] | [-8.18] | [-16.73] |
| Europe Lag | 0.11\*\*\* | 0.13\*\*\* | 0.09\*\* | 0.11\*\*\* |
|   | [3.02] | [3.61] | [2.37] | [4.96] |
| London/New York Lag | 0.06\*\* | 0 | -0.02 | 0.01 |
|  | [2.11] | [0.13] | [-0.51] | [0.73] |
| U.S. Lag | 0.05 | 0.06\*\* | 0.17\*\*\* | 0.1\*\*\* |
|   | [1.62] | [2.48] | [5.77] | [5.9] |
| Asia Lag | 0.2\*\*\* | 0.21\*\*\* | 0.3\*\*\* | 0.25\*\*\* |
|   | [5.75] | [8.58] | [9.18] | [15.2] |
| Weekly Lag | 0.35\*\*\* | 0.41\*\*\* | 0.21\*\*\* | 0.31\*\*\* |
|   | [5.48] | [7.04] | [3.93] | [9.19] |
| Monthly Lag | 0.18\*\*\* | 0.2\*\*\* | 0.3\*\*\* | 0.19\*\*\* |
|   | [3.94] | [4.3] | [6.06] | [6.8] |
| Expected Trades | 0.23\*\*\* | 0.02 | 0.04 | -0.03\*\*\* |
|  | [3.64] | [0.66] | [1.14] | [-3.79] |
| Unexpected Trades | 0.64\*\*\* | 0.49\*\*\* | 0.3\*\*\* | 0.48\*\*\* |
|   | [12.96] | [15.79] | [5.41] | [20.78] |
| Expected Order Imbalance | 25.78 | 15.02 | 0.53 | 0.74 |
|  | [0.56] | [1.25] | [0.47] | [0.58] |
| Unexpected Order Imbalance | -2.6 | -1.62 | -0.3\*\*\* | -0.34\*\*\* |
|   | [-0.66] | [-1.6] | [-3.15] | [-3.07] |
| $$\overbar{R}^{2}$$ | 0.62 | 0.48 | 0.64 | 0.60 |

**Panel B. Europe**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | 1996 to 1999 | 2000 to 2007 | 2008 to 2012 | Full Sample |
| Intercept | -3.15\*\*\* | -2.77\*\*\* | -0.84\*\* | -1.88\*\*\* |
|   | [-8.69] | [-16.17] | [-2.48] | [-18.95] |
| Europe Lag | 0.13\*\*\* | 0.14\*\*\* | 0.16\*\*\* | 0.18\*\*\* |
|   | [3.95] | [5.61] | [4.8] | [10.64] |
| London/New York Lag | 0.03 | 0.03 | 0.02 | 0.04\*\*\* |
|  | [1.14] | [1.37] | [0.57] | [2.91] |
| U.S. Lag | -0.04 | 0.03 | 0.1\*\*\* | 0.03\*\* |
|   | [-1.51] | [1.4] | [3.89] | [1.97] |
| Asia Lag | 0.26\*\*\* | 0.16\*\*\* | 0.32\*\*\* | 0.21\*\*\* |
|   | [8.9] | [9.9] | [12.53] | [16.66] |
| Weekly Lag | 0.4\*\*\* | 0.24\*\*\* | 0.03 | 0.23\*\*\* |
|   | [7.33] | [6.23] | [0.64] | [8.64] |
| Monthly Lag | 0.18\*\*\* | 0.18\*\*\* | 0.39\*\*\* | 0.26\*\*\* |
|   | [4.21] | [5.35] | [9.01] | [11.9] |
| Expected Trades | 0.26\*\*\* | 0.04\*\* | -0.05 | 0.02\*\*\* |
|  | [4.69] | [2.46] | [-1.3] | [3.42] |
| Unexpected Trades | 0.78\*\*\* | 0.48\*\*\* | 0.08 | 0.5\*\*\* |
|   | [17.62] | [17.36] | [1.35] | [23.15] |
| Expected Order Imbalance | 14.54 | -9.98\*\* | -0.92\* | -1.08\* |
|  | [0.87] | [-1.97] | [-1.66] | [-1.83] |
| Unexpected Order Imbalance | -0.92 | -1.04\*\* | -0.16\*\*\* | -0.17\*\*\* |
|   | [-0.6] | [-2.28] | [-3.1] | [-3.08] |
| $$\overbar{R}^{2}$$ | 0.65 | 0.47 | 0.59 | 0.64 |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Panel C: London/New York** |  |  |  | *Table IV continued* |
| Variable | 1996 to 1999 | 2000 to 2007 | 2008 to 2012 | Full Sample |
| Intercept | -3.6\*\*\* | -2.01\*\*\* | -1.64\*\*\* | -1.65\*\*\* |
|   | [-8.76] | [-8.4] | [-4.27] | [-11.75] |
| Europe Lag | 0.26\*\*\* | 0.36\*\*\* | 0.51\*\*\* | 0.39\*\*\* |
|   | [6.23] | [12.34] | [12.99] | [19.24] |
| London/New York Lag | -0.02 | 0.06\*\* | 0.05 | 0.06\*\*\* |
|  | [-0.5] | [2.31] | [1.42] | [3.42] |
| U.S. Lag | 0.08\*\* | 0.07\*\*\* | 0.07\*\* | 0.08\*\*\* |
|   | [2.13] | [3.11] | [2.28] | [4.49] |
| Asia Lag | 0.06 | 0.08\*\*\* | 0.09\*\*\* | 0.06\*\*\* |
|   | [1.52] | [3.74] | [2.74] | [3.75] |
| Weekly Lag | 0.34\*\*\* | 0.16\*\*\* | 0.13\*\* | 0.2\*\*\* |
|   | [4.89] | [3.53] | [2.4] | [6.36] |
| Monthly Lag | 0.18\*\*\* | 0.24\*\*\* | 0.1\* | 0.21\*\*\* |
|   | [3.13] | [5.6] | [1.79] | [7.56] |
| Expected Trades | 0.17\*\*\* | 0.06\*\* | 0.05 | 0.00 |
|  | [2.78] | [1.98] | [0.89] | [-0.09] |
| Unexpected Trades | 0.53\*\*\* | 0.31\*\*\* | 0.47\*\*\* | 0.35\*\*\* |
|   | [12.86] | [14.55] | [7.86] | [19.74] |
| Expected Order Imbalance | -0.36 | 2.08 | 0.80 | 0.73 |
|  | [-0.04] | [0.46] | [0.75] | [0.67] |
| Unexpected Order Imbalance | -0.26 | -0.02 | -0.37\*\*\* | -0.34\*\*\* |
|   | [-0.34] | [-0.04] | [-3.75] | [-3.39] |
| $$\overbar{R}^{2}$$ | 0.54 | 0.44 | 0.54 | 0.56 |

**Panel D: United States**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Variable | 1996 to 1999 | 2000 to 2007 | 2008 to 2012 | Full Sample |
| Intercept | -3.2\*\*\* | -2.21\*\*\* | -0.4 | -1.34\*\*\* |
|   | [-8.99] | [-9.91] | [-1.23] | [-10.84] |
| Europe Lag | 0.08\*\* | 0.2\*\*\* | 0.22\*\*\* | 0.16\*\*\* |
|   | [2.46] | [6.89] | [5.31] | [8.38] |
| London/New York Lag | 0.2\*\*\* | 0.33\*\*\* | 0.38\*\*\* | 0.31\*\*\* |
|  | [7.41] | [13.94] | [12.35] | [19.66] |
| U.S. Lag | 0.04 | 0.08\*\*\* | 0.1\*\*\* | 0.12\*\*\* |
|   | [1.32] | [3.95] | [3.56] | [7.87] |
| Asia Lag | 0.12\*\*\* | 0.06\*\*\* | 0.16\*\*\* | 0.11\*\*\* |
|   | [3.87] | [2.97] | [4.82] | [6.99] |
| Weekly Lag | 0.22\*\*\* | 0.11\*\*\* | 0.05 | 0.1\*\*\* |
|   | [4.07] | [2.75] | [0.98] | [3.49] |
| Monthly Lag | 0.17\*\*\* | 0.07\* | 0.03 | 0.05\* |
|   | [3.81] | [1.77] | [0.62] | [1.88] |
| Expected Trades | 0.22\*\*\* | 0.16\*\*\* | 0 | 0.01 |
|  | [4.54] | [6.48] | [0.07] | [1.29] |
| Unexpected Trades | 0.61\*\*\* | 0.44\*\*\* | 0.36\*\*\* | 0.44\*\*\* |
|   | [18.27] | [23.3] | [6.24] | [28.28] |
| Expected Order Imbalance | -1.34 | -5.51 | -0.63 | -0.74 |
|  | [-0.26] | [-1.55] | [-0.86] | [-1.03] |
| Unexpected Order Imbalance | -0.45 | -1.71\*\*\* | -0.25\*\*\* | -0.31\*\*\* |
|   | [-0.68] | [-3.4] | [-2.67] | [-3.38] |
| $$\overbar{R}^{2}$$ | 0.62 | 0.55 | 0.61 | 0.60 |

**Table VI**

**Private Information Shares**

This table reports the average private information flows in different markets (Asia, Europe, London/New York or U.S.) and sub periods. We first estimate coefficient estimates from equation (5). Daily private information flow by exp($\hat{β}\_{i,T}^{u}T\_{i,t}^{u }$+$ \hat{β}\_{i,Z}^{u}Z\_{i,t}^{u}$). Panel A reports private information flows. Panel B reports hourly information shares of the private information flows and Panel C reports the statistical differences between markets of hourly information shares of private information flows. The *t-*statistics are in the square brackets with asterisks \*\*\*, \*\*, and \* indicating significant at 1%, 5%, and 10% respectively.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Asia | Europe | LNY | U.S. |
| Panel A: Average Private Information Flow |  |  |  |
| 1996-1999 | 0.901 | 1.102 | 0.979 | 1.082 |
| 2000-2007 | 0.898 | 1.104 | 0.979 | 1.079 |
| 2008-2012 | 0.833 | 1.171 | 0.972 | 1.113 |
| Full Sample | 0.88 | 1.123 | 0.977 | 1.09 |
|  |  |  |  |  |
| Panel B: Average Private Information Share (%) |  |  |
| 1996-1999 | 22.2 | 27.1 | 24.1 | 26.6 |
| 2000-2007 | 22.1 | 27.2 | 24.1 | 26.6 |
| 2008-2012 | 20.4 | 28.6 | 23.8 | 27.2 |
| Full Sample | 21.6 | 27.6 | 24.0 | 26.8 |
|  |  |  |  |
| Panel C: Average Per-hour Private Information Share (%) |  |  |
| 1996-1999 | 2.77 | 3.87 | 12.0 | 3.80 |
| 2000-2007 | 2.76 | 3.88 | 12.1 | 3.80 |
| 2008-2012 | 2.55 | 4.09 | 11.9 | 3.89 |
| Full Sample | 2.70 | 3.94 | 12.0 | 3.83 |
|  |  |  |  |

1. \* Corresponding author at: Finance Discipline Group, University of Technology Sydney, Sydney NSW 2007, Australia. Tel: +61 2 9514 9744. E-mail address: jianxin.wang@uts.edu.au [↑](#footnote-ref-1)
2. <http://www.lbma.org.uk/the-london-bullion-market> [↑](#footnote-ref-2)
3. [Thomson Reuters (2014](#_ENREF_28)). [↑](#footnote-ref-3)
4. The two hours are 2 to 4 pm London local time and 9 to 11 am New York time. [↑](#footnote-ref-4)
5. See for example [Lin, Sanger and Booth (1995](#_ENREF_27)), [Huang and Stoll (1997](#_ENREF_22)), [Madhavan, Richardson and Roomans (1997](#_ENREF_30)), [Easley, Kiefer and O'Hara (1997](#_ENREF_16)) and [Easley, de Prado and O'Hara (2012](#_ENREF_14)). [↑](#footnote-ref-5)
6. According to Wikipedia, the idea of the gold ETF was first conceptualized in India in May 2002. The first gold ETF was listed in March 2003 on the Australian Securities Exchange. [↑](#footnote-ref-6)
7. Here is a brief summary of Reuters' contributor criteria: New contributors must contribute for a period not less than 2 months. Contributors must be financial or gold trading institutions with a Standard & Poors creditor of "BBB" or higher. New contributors must gain at least 51% voting approval by existing contributors on the question of whether the candidate is to be allowed to contribute. Also the new contributor must gain at least 50% of votes by the LBMA Gold Market-Making Member Community. As an existing contributor, the contributor must input prices at least five times in a space of a trading day for the country in which they are located and not to be clustered together in any one single hour period. Contributors must insert quotes within 0.5% of the previous quote in order to meet quality parameters unless major and sudden market movements justify a larger immediate jump. If rules are not followed Reuters may block the contributor from contributing. Details of the criteria are presented in the TRTH speed guide page 'PRECIOUS/RULES'. [↑](#footnote-ref-7)
8. While there are methods to estimate the information share of each market during the overlapping hours, we do not have the necessary data on the location of each contributor. [↑](#footnote-ref-8)
9. The *t*-statistics for the difference in the coefficient for lagged Asia (0.21) and lagged Europe (0.18) is 11.4. [↑](#footnote-ref-9)