Who sets the price of gold? London or New York [*]

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Abstract

We investigate which of the two main centers of gold trading – the London spot market and the New York futures market – plays a more important role in setting the price of gold. Using intraday data during a 17-year period we find that although both markets contribute to price discovery, the New York futures play a larger role on average. This is striking given the volume of gold traded in New York is less than a tenth of the London spot volume, and illustrates the importance of market structure on the process of price discovery. We find considerable variation in price discovery shares both intraday and across years. The variation is related to the structure and liquidity of the markets, daylight hours, and macroeconomic announcements that affect the price of gold. We find that a major upgrade in the New York trading platform reduces the relative amount of noise in New York futures prices, reduces the impact of daylight hours on the location of price discovery, but does not greatly increase the speed with which information is reflected in prices.

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1. Introduction

Gold is one of the most traded assets worldwide. In 2011, the estimated daily turnover in the international gold market was 4,000 metric tons, equivalent to over $240 billion. This is approximately the same as the daily dollar volume of trade on all of the world's stock exchanges combined.[1] The turnover in the gold market exceeds turnover in all but four currency pairs.[2] The two major centers for gold trading, the London over-the-counter (LOTC) spot market and the New York Mercantile Exchange Futures Market (COMEX), account for approximately 78.0% and 7.7% of the total gold turnover, respectively. Although gold futures account for a smaller proportion of total turnover, studies in other markets show that futures play an important role in price discovery (Bohl et al., 2011; Boyd & Locke, 2014; Dolatabadi et al., 2015; Rosenberg & Traub, 2009). Despite the enormous size of the international gold market, somewhat surprisingly, relatively little is known about how information is incorporated into gold prices. This paper aims to fill this void.

Gold trade internationally is largely decentralized, with physical gold traded in OTC markets and financial securities linked to gold (including futures, options and other derivatives) traded on organized exchanges and trading platforms worldwide.[3] Understanding the price formation process and where/how information about the value of gold is impounded into its price is paramount to investors and regulators due to the great economic significance of gold. The introduction of new capital requirements for banks have brought attention to the pivotal role that liquid assets play in bank risk management, and in particular to the role that gold can play in diversifying a firm's liquid assets.

In this paper we answer two main questions: where do innovations in the price of gold originate, and how has this changed over time? In contrast to many other assets, information that affects the value of gold is generated in many different places, including mines, jewelry demand, investment requirements, central bank actions, and macroeconomic conditions. If information can be generated practically anywhere, no trading location will have a clear localization

[1] According to the World Federation of Exchanges 2011 Annual Report (available at http://www.world-exchanges.org/files/statistics/pdf/2011_WFE_AR.pdf), the total value of all equities trades in electronic order books (stock exchanges) around the world in 2011 is $63 trillion, which, assuming 220 trading days per year, is a daily turnover of around $287 billion.

[2] The four currency pairs include USD/EUR, USD/YEN, USD/GBP and USD/AUD with turnover figures of $1,101 billion, $568 billion, $360 billion and $249 billion respectively (Report on global foreign exchange market activity in 2010).

[3] The emergence of the gold market is described in O'Callaghan (1991).

advantage, which is an important consideration in equity price discovery (Anand et al., 2011). Furthermore, the large distances between the different trading locations for gold gives rise to relatively high latency in information transmission and limits high frequency trading (Frino et al., 2014). We use intraday data on gold prices in the UK OTC and the US futures market during the period 1997 – 2014. This allows us to examine variation in price discovery through the course of several years and examine the effects of market structure changes during our sample, as well as analyze the intraday patterns in price discovery and the process by which specific news announcements are impounded into prices.

A striking result of our analysis is that although the volume of gold traded in the UK OTC spot market is more than ten times higher than that of the US futures market (78.0% market share compared to 7.7%), the futures market tends to play a more important role in incorporating new information about the value of gold. This result highlights the importance of market structure and instrument type. Our results support the notion that the centralization and relatively transparency of the futures market contribute to its disproportionately large role in price discovery. It is also likely that the low transaction costs, inbuilt leverage and ability to avoid dealing with the underlying asset, make futures contracts an attractive option for those that trade gold as a financial asset, and such trades contribute disproportionately to price discovery.

Our second key finding further reinforces the impact of market structure on the process of price discovery. During our sample period, in 2006, the US futures market (COMEX) moved from an open outcry floor-based system to the fully electronic, nearly 24-hour GLOBEX platform. We find that this change notably decreases the level of microstructure noise in US futures prices relative to the UK spot prices, but does not have a large impact on the futures market's contribution to impounding new information about the price of gold.

Our third key finding is that although the US futures market leads with respect to price discovery overall, several factors affect the extent to which it leads. Our results indicate that price discovery shares vary substantially at both the daily and intraday levels, with the two markets changing their relative importance throughout the day and from day to day. Prior to the US futures market's move to the fully electronic GLOBEX platform in 2006, the price discovery shares of the two major trading centers are largely dictated by daylight hours within each market locale – the UK OTC market plays a more important role during UK daylight hours and the US futures market plays a more important role during US daylight hours. When the COMEX commenced trading on the GLOBEX platform, intraday variation in price discovery declines and COMEX takes a consistent lead throughout the day irrespective of market hours. This finding illustrates how highly accessible electronic platforms can decrease the importance of geographic location and create a more integrated global market.[4]

We hypothesize that some of the variation in daily and intraday price discovery shares is related to specific news events that affect the value of gold, including the UK gold fixing and various macroeconomic announcements (Hautsch et al., 2011). The information contained in specific announcements may have a tendency to be incorporated into specific markets, generating variation in price discovery shares. The UK gold fixing is ‘leaky’ in that information about the fix is leaked to market participants before the fixing process is completed (Caminschi & Heaney, 2014) and such information may affect the location of price discovery. To examine these possibilities, we regress price discovery shares on dummy variables for gold fixing times and various macroeconomic announcements. We find weak evidence that the gold fixing increases the UK OTC market’s share of price discovery. Also, our results indicate that US GDP and PPI announcements are associated with an increase in the US futures market’s share of price discovery, whereas US employment announcements including Non-Farm Payroll are associated with an increase in noise but not price discovery share for either market. UK announcements in general have no effect on the location of price discovery, although some are associated with an increase in noise in the LOTC.

Our findings contribute to the literature on how different market structures and instrument types affect the nature of price discovery. It is generally accepted that futures contracts lead their respective underlying assets in price discovery (Bohl et al., 2011; Rosenberg & Traub, 2009), yet this relationship has not been confirmed in the gold market despite its immense size and economic impact. Cabrera et al. (2009) find that foreign exchange spot quotes consistently lead foreign exchange futures prices. The gold and foreign exchange markets are similar in that the spot market accounts for a substantial share of trading activity, and therefore the findings of Cabrera et al. (2009) suggest that ex-ante it is not obvious that gold futures would lead the spot market in price discovery. Other studies of gold price discovery include comparisons between COMEX Futures and Tokyo Commodities Exchange Futures (Xu & Fung, 2005; Lin et al., 2008) and Indian gold futures (Fuangkasem et al., 2014). These studies conclude that COMEX

[4] The efficacy of floor and electronic trading is investigated by Ates and Wang (2005)

dominates price discovery, which in addition to its considerable volume, is why we choose to compare gold prices from COMEX with those in the UK spot market. Lucey et al. (2013) compare the LOTC market and COMEX using daily data and find that price leadership shifts between the two markets. Our use of intraday data allows for more accurate measurement of price discovery (following from Hasbrouck (1995) most price discovery studies use a sampling frequency of one second), and a richer characterization of intraday patterns and determinants of price discovery.

Our study also contributes to the literature on gold. Prior research in this area is concerned with the hedging value of gold and whether it can be considered a safe haven (Baur & Lucey, 2010; Baur & McDermott, 2010; Capie et al., 2005), the relation between gold and other precious metals (Batten et al., 2010), psychological price barriers in gold (Aggarwal & Lucey, 2007) and its investment value (Hillier et al., 2006; Sherman, 1982). This is the first study to use intraday data to estimate price discovery metrics for gold during a long time period. While other papers have investigated price discovery in the gold market, these papers have not examined the LOTC spot market, which accounts for 78.0% of global trade.

This paper proceeds as follows. Section 2 discusses the structures of the LOTC and COMEX. Sections 3, 4 and 5 describe the data, method, and results, respectively, and Section 6 concludes.

2. Market structure

COMEX and the LOTC markets are structurally different. COMEX is a centralized exchange in which all orders are routed through one system. The LOTC market on the other hand is a decentralized over-the-counter dealer market in which a number of dealers each quote bid and ask prices. In this section we explain in greater detail the structures of these two markets, and more specifically, the structure of the instruments that are of interest to this paper.

Participants in the LOTC comprise market-making members and ordinary members. Major international banks make up 12 of the 13 market-making members and are required by the London Bullion Market Association (LBMA) to provide two-way quotes during London market hours, and whenever the New York market is closed. Ordinary members comprise companies that are operational in areas that are closely related to the physical gold itself, including trading, broking, shipping and storage, mining, refining, inspection and assaying and research. Trading occurs between members of both types. This membership restriction leads to a market with few highly specialized participants representing clients internationally. In 2011, there were 56 full members in this market (Murray, 2011).

The usual minimum transaction size is 2,000 fine troy ounces for gold (LBMA, 2014), and typical transactions between market makers are 5,000 ounces. Quotes are in US dollars per fine troy ounce with a minimum tick size of one cent. Fine gold content represents the true quantity of gold in a bar, which may be less than the total bar weight due to impurities.

Transparency in the LOTC market is low. There is no public record of trade volumes or prices, only the quotes are observable. The lack of transparency is the major motivation of the Loco London Liquidity Survey (Murray, 2011) which endeavors to show that gold is a “high quality liquid asset”. The only figures published on a regular basis by the LOTC market are monthly clearing statistics, based on returns from the six clearing members that form the London Precious Metals Clearing Company. The LOTC does not require its members to report turnover and other related statistics.

COMEX is a futures exchange that trades many commodities. Individuals and firms can trade and membership requirements are less stringent than the LOTC. Requirements for individual membership include good moral character and business integrity (CME Group, 2014). Corporate membership is open to various company types and requires some ownership stake in the equity of the exchange.

Each gold futures contract on COMEX represents 100 troy ounces (CME, 2014) and is quoted in US dollars per troy ounce. Delivery takes place on any business day within the delivery month, but not later than the last business day of the delivery month. Gold delivered under this contract needs to meet the 995 minimum fineness requirements. Minimum tick size on these contracts is 10 cents per troy ounce.

Most volume in the COMEX gold futures market is in contracts that are marked Trading At Settlement (TAS). TAS allows traders to commit to a trade without knowing the price at which it will settle. A trader submits an order at any time, with this order matched to a countering order. The trade is finally settled at the settlement price which is determined by the exchange at 13:30 Eastern Time. This method essentially allows for a trade to occur at a price that is determined in the future. On the one hand, this added uncertainty allows uninformed liquidity traders to trade on a more equal level with the informed, as neither party should know what the final settlement price will be. Informed traders can use TAS in order to arbitrage any intraday price deviations. With sufficient informed trade, the price at any time should be indicative of the future settlement price. TAS orders are only available on five contract months, deemed Active Months (CME, 2014). These months are February, April, June, August and December, representing every two months except for a break in October. In any given month, the most actively traded contract is the one closes to expiry.

Transparency in the COMEX futures market is much greater than in the LOTC. Although traders are anonymous, bid and ask depth is available for ten levels. Partially hidden orders are also available through ice-berg orders, with each new segment being placed at the bottom of the order book when each public segment is executed (CME, 2014).

Overall, the wholesale nature of the LOTC market is very different to the open retail exchange system available through COMEX. With major differences in products, trade sizes, centrality and participants, we expect that the contributions to price discovery of the New York futures and London spot markets come from different sources. These two markets constitute an interesting cross-border environment in which to study the price discovery of gold.

3. Data

Our study compares futures contracts traded on COMEX and gold spot quotes from LOTC. Since accurate estimations of information shares can only be achieved through the use of very high frequency data, we use trade and quote data sampled at a one-second frequency.

We obtain intraday and trade and quote data for the futures contracts and the LOTC market from *Thomson Reuters Tick History*. Our data include the best (inside) bid and ask quotes in each market, time-stamped to the millisecond. From the best bid and ask quotes, we calculate the midquote (the simple average of the bid and ask quotes at that point in time), which reduces the effects of bid-ask bounce. Using these data, we identify the most actively traded futures contract for any given day, illustrated in Table 1. Delivery on gold futures contracts can be made on any day within their expiry month, and consequently the contracts stop trading at the start of the expiry month. Intuitively, contract holders would like to take delivery as early as possible. We find that volume shifts to the next closest contract expiry two days before the front futures contract becomes deliverable. For example, the most traded contract throughout most of January is the one closest to expiry (February contract), but two days before the end of January volume shifts to the next contract expiry (April contract) as traders manage their portfolios in preparation for delivery by either closing their position for a cash return or holding the contract to receive physical delivery. On this basis, we create a futures price series that uses the most actively traded contract at every point in time. This price series is converted into a one-second sampled time series. Similarly, we convert the intraday quotes for the LOTC gold spot market to one-second increments. The two midquote series are merged by date and time, resulting in one time series of two prices.

< Insert Table 1 here >

The benefit of using the LOTC gold spot market and the COMEX futures market is that both trade almost 24 hours per day, presenting ample time in which both markets overlap. COMEX gold futures trade in an electronic exchange setting from Sunday to Friday, with a break from 17:15 to 18:00 New York time. The LOTC on the other hand allows continuous trading through their inter office telephone service in an OTC setting, with indicative quotes from members available at all times. Summer and winter time changes in the US cause a shift in the concurrent trading of the two markets. New York time shifts between -4h GMT and -5h GMT. Converting the COMEX break period to GMT yields 21:15 to 22:00 in summer and 22:15 to 23:00 in winter. To simplify the calculation and to ensure both markets are trading concurrently for the entire sample we eliminate all trades and quotes after 20:00 GMT. This also eliminates a short period of time around the opening and closing of COMEX, which is consistent with the approach taken in other intraday microstructure studies.

Macroeconomic announcements for both the UK and US are extracted from Bloomberg. The data include the announcement content and announcement time-stamp for major economic announcements including GDP, central bank target rate, employment figures (including Non-Farm Payroll for US), PPI and CPI. We use these announcements to generate dummy variables with a value of one at the time of release, and zero otherwise.

Our sample period extends from January 1, 1997 to November 30, 2014. In total this includes 3,872 trading days and 51,702,414 one-second observations.

The gold spot market is large, with most trades occurring in UK OTC market. Due to the nature of OTC markets, trade volumes are not reported making it difficult to measure the size of the gold spot market. Table 2 illustrates the trade in gold in each of the six major gold trading countries. These estimates are sourced from Lucey et al. (2013) (who use Murray (2011) and GFMS Ltd. (2012) data) and reflect trading in all gold-related instruments (including spot and gold derivatives).

< Insert Table 2 here >

Table 2 illustrates that the UK accounts for approximately 87% of the combined volume of gold trading in the six main gold trading countries, with 90% of this being in the spot market. According to the Loco London Liquidity Survey (Murray, 2011), the daily turnover on the London gold spot market alone is in excess of $216 billion, which is comparable in value to US-Australian and US-Canadian dollar foreign exchange settlements (based on 2010 data in Bank for International Settlements, 2011), as well as the daily turnover of all stock exchanges in the world. The average daily dollar volume of the front futures contract over the same period is approximately $22 billion, illustrating the size disparity between our markets.

4. Method

Our aim in this paper is to analyze where information enters the gold market, and how this has changed over time. We begin with two measures that are widely used in the price discovery literature, namely the Hasbrouck (1995) Information Share (*IS*) and the Gonzalo and Granger (1995) Component Share (*CS*). Fundamentally, both *IS* and *CS* decompose price innovations into permanent and temporary components. They are estimated using a Vector Error Correction Model (VECM):

$$\Delta p_{1,t} = \alpha_1\left(p_{1,t-1} - p_{2,t-1}\right) + \sum_{i=1}^{200} \gamma_i \Delta p_{1,t-i} + \sum_{j=1}^{200} \delta_j \Delta p_{2,t-j} + \varepsilon_{1,t} \quad (1)$$

$$\Delta p_{2,t} = \alpha_2\left(p_{1,t-1} - p_{2,t-1}\right) + \sum_{k=1}^{200} \varphi_k \Delta p_{1,t-k} + \sum_{m=1}^{200} \phi_m \Delta p_{2,t-m} + \varepsilon_{2,t} \quad (2)$$

where $\Delta p_{i,t}$ represents the change in the log price of the asset traded in market i for time period t. Appendix A outlines the calculation of *IS* and *CS* from the VECM model above.

Recent studies of how to measure price discovery show that *IS* and *CS* both are sensitive to the relative level of noise between two markets – they measure a combination of leadership in impounding new information (what price discovery metrics aim to measure), and the relative level of noise in the price series (Yan & Zivot, 2010; Putniņš, 2013). Consequently, *IS* and *CS* tend to overstate the price discovery contribution of the less noisy market. Of the two, *IS* places greater weight on the speed at which a price series impounds new information, compared to the *CS* metric which is largely a measure of the relative levels of noise. It is likely that the levels of noise in the prices of the two markets examined in this paper are vastly different considering their differences in liquidity levels, market structure and instrument types. Therefore, it is important to keep in mind the sensitivity of *IS* and *CS* to differences in microstructure noise when interpreting the results.

An important insight of the recent price discovery literature is that a combination of *IS* and *CS* is able to correctly attribute contributions to price discovery without being influenced by differences in noise levels. Intuitively, *IS* and *CS* can be combined such that their dependence on noise cancels out. This measure, known as the Information Leadership Share (*ILS*), developed in Yan and Zivot (2010) and Putniņš (2013), is calculated as follows:

$$ILS_1 = \frac{\left|\frac{IS_1 CS_2}{IS_2 CS_1}\right|}{\left|\frac{IS_1 CS_2}{IS_2 CS_1}\right| + \left|\frac{IS_2 CS_1}{IS_1 CS_2}\right|}, \; ILS_2 = \frac{\left|\frac{IS_2 CS_1}{IS_1 CS_2}\right|}{\left|\frac{IS_1 CS_2}{IS_2 CS_1}\right| + \left|\frac{IS_2 CS_1}{IS_1 CS_2}\right|} \quad (3)$$

We estimate all three price discovery metrics, noting that they measure different aspects of price discovery.

5. Results

5.1 Daily results

We estimate the price discovery measures for each trading day over our sample period using a one-second sampling frequency. Table 3 reports the annual averages of the daily price discovery shares for the futures market (the spot market price discovery shares are simply one minus the futures market share), and Figure 1 illustrates the trends through time using a 180-day moving average. The *IS* and *CS* measures at the start of the sample are only slightly above 50% (67% and 61%, respectively). *IS* rises steadily until 2006, after which it remains consistently above 90%. *CS* also increases sharply after 2006 and remains very high for the remainder of the sample period.

ILS tells a slightly different story. The futures market in the first year of our sample has an *ILS* of 66%, which rises above 85% for the years 2003 to 2007, after which it falls slightly and remains stable around 70%. Due to its insensitivity to differences in noise, the *ILS* estimates paint the clearest picture of trends in impounding new information. It indicates that in each of the past 17 years, the futures market has been a more important source of gold price discovery overall than the UK spot market and that its contribution has increased slightly since the start of the sample. The fact that *IS* and *CS* tend to increase sharply after 2006 and this increase is not reflected in *ILS* suggests that the futures market experienced a substantial decline in the relative amount of noise in its prices compared to the spot market.

< Insert Table 3 here >

< Insert Figure 1 here >

Such a distinct change in the above price discovery metrics begs further explanation. Using higher frequency aggregations to make the above tables, it becomes apparent that the shift occurs at the end of 2006. The likely cause is a substantial change in the structure of trading at COMEX during the last two months of 2006. At this time COMEX opened electronic trading alongside floor trading. Before the change, the bulk of the trading volume on COMEX was generated by the trading floor in an open outcry system. Outside of the floor hours, COMEX used NYMEX's Access electronic trading platform with floor and electronic hours not overlapping (Morrison, 2006). This change was made primarily to stay competitive with other exchanges, which were providing electronic trading at this time (Goodman, 2011). This shift further resulted in the adoption of the GLOBEX platform, which provided near 24-hour electronic trading at high speeds internationally. This move to an international electronic exchange was complemented by an international incentive programs which allowed traders outside the US to trade at lower costs (CME Group, 2014).

Beginning on December 3, 2006, COMEX expanded its metals electronic trading to include side by side trading of Asian and London metals futures contracts (CME Group Media Room, 2014). This parallel trading of international futures contracts greatly enhances the attractiveness of COMEX. Intuitively, if the GLOBEX platform is superior in trading costs and execution times, this would decrease the amount of microstructural noise, leading to the increase in both *IS* and *CS* that is present in the data.

This change in the structure of the COMEX market flows through to the volume of contracts traded. Figure 2 illustrates the daily average volume of contracts traded for the most active contract at ever point in time. There is a clear increase in the number of contracts traded on COMEX, and there is a stark increase after the structural change in 2006. Intuitively, greater volume leads to greater liquidity and lower spreads, causing the shift in *IS* and *CS*, which is evident in our results.

< Insert Figure 2 here >

Intuitively, the increase in futures market volume is also likely to affects the average bid-ask spread. Figure 3 illustrates a moving average of the spreads in each of the two markets during our sample period. There is a distinct reduction in the spread of COMEX at the end of 2006. Interesting, at the same time, there is a corresponding increase in the spread of LOTC, suggesting that perhaps some of the volume from LOTC migrated to COMEX after the upgrade of the COMEX platform and implementation of international incentive programs. Unfortunately, due to the absence of a time series of LOTC volumes we are unable to further investigate this conjecture. At many times the futures market spread is constrained by its minimum tick size of ten cents. The LMBE however is not limited by its minimum tick size of one cent.

< Insert Figure 3 here >

The evidence in this section is consistent with the notion that the change in the market structure of COMEX led to significant changes in the global gold market. A more accessible, electronic 24-hour market with low costs and fast execution lends itself greatly informed traders, speculators and hedgers. All three measures of price discovery show that the COMEX futures market provides a greater share of gold price discovery.

5.2 Intraday results

In this section we examine intraday patterns in price discovery by estimating the three metrics in each hour of each day. Because London and New York are in vastly different time zones, we test the effect of time zone on price discovery. London is either four or five hours ahead of New York, depending on the time of year. Consequently, for up to five hours of the

London working day, New York may not yet have started work, and at the end of the day, London would finish work five hours before New York.

This leads to the interesting question of whether COMEX leads price discovery even when most of the local population is asleep? Our results indicate that this is the case in more recent years, but it has not always been so. Figure 4 illustrates the average intraday price discovery measures each hour for a few indicative years. The years 1998 and 2005 are representative of the intraday trends for all other years in between – this is the period before the significant trading platform upgrades in COMEX. Similarly, 2007 and 2013 are representative of the intraday trends from 2007 onwards, after the market structure change.

< Insert Figure 4 here >

Figure 4 shows that at the beginning of our sample, there is a clear and distinct shift in informational leadership and price discovery throughout the day. The opening of floor trading at COMEX around 13:20 GMT (12:20 GMT) is associated with a substantial increase in the price discovery share of the futures market. This increase diminishes when floor trading ends at 18:30 GMT (17:30 GMT). In other words, the intraday period during which the COMEX floor is open is associated with substantially more price discovery occurring in the US.

From 2007 onwards, after COMEX introduced the new near 24-hour electronic GLOBEX platform, the intraday patterns are substantially different. There are no longer clear intraday shifts in the price discovery shares and instead, the price discovery shares remain relatively stable throughout the day. The impact of thee floor opening hours is no longer present from 2007. Daylight or working hours no longer affect the location of price discovery.

5.3 Determinants of price discovery

In this section we test various determinants of gold price discovery shares, adding multivariate statistical evidence to support the casual observations made in previous sections. We also examine whether different types of macroeconomic news tend to be impounded in one or the other market. To do this we estimate time-series regressions in which the dependent variable is the futures market's (COMEX) share of gold price discovery, measured each hour. A positive coefficient for an independent variable signifies that variable increases the future market's share of price discovery.

< Insert Table 4 here >

Table 4 reports the regression results. AFTERMCHANGE is equal to one after the shift of COMEX onto the GLOBEX trading platform. ASIA, USA and UK are dummy variables equal to one when the largest equity market in that region is open, which is a proxy for that region's business hours. AMFIX and PMFIX are dummy variables that equal one during the hour of the AM and PM London gold price fixing. The AM and PM fixings occur at 10:30am and 3:00pm UK time, respectively. The UKBANKRATE and USBANKRATE are dummy variables that equal one during hourly periods that contain announcements from UK and US central banks regarding target interest rates. Similarly UKEMPLOY and USEMPLOY are dummy variables for national employment announcements in the UK and US. UKGDP, USGDP, UKPPI, USPPI, UKCPI, and USCPI are dummy variables for GDP, PPI and CPI announcements made by the UK and US. With all our dummy variables, if the event occurs exactly on the hour, the dummy variable is equal to one for that hour. For example, the PM fixing occurs at 3:00pm, so PMFIX is equal to one for the 3:00pm to 4:00pm hourly interval. Our *t*-statistics are calculated using Newey-West corrected standard errors.

Table 4 reports the regression results. The COMEX trading platform upgrade (AFTERMCHANGE) has a highly significant effect on all price discovery measures. According to the regressions, *CS*, *IS*, and *ILS* increase by 19, 22, and 3 percentage points respectively after the change, holding other variables constant. These multivariate results support our earlier observations that the platform upgrade has a large impact on the liquidity and thus level of microstructure noise in the futures prices (reducing noise relative to the spot market), but does not have a large impact on the overall contribution of the futures market to impounding new information. The former conclusion follows from the large increases in *CS* and *IS*, and the latter from the small increase in *ILS*.

The variables measuring business hours in the three regions, ASIA, USA and UK, are statistically significant determinants of the intraday price discovery shares. The coefficients for USA and UK are positive, suggesting that the futures market increases in contribution to price discovery during US and UK business hours. The coefficient associated with ASIA is less significant, smaller and negative in the case of two price discovery measures, suggesting that the opening of the ASIAN market does not impact the location of gold price discovery to a great extent.

The UK gold fixing is known to affect the price of gold, however, our results indicate that its effect on the *location* of price discovery is minimal. The AMFIX coefficient is marginally significant and close to zero for the *ILS* regression, providing weak evidence that there is a shift to LOTC for this event. The PMFIX coefficients for the *CS* and *IS* regressions are highly significant and positive, indicating that the relative level of noise between our two markets changes around the time of the fixing. We interpret this as an increase in the level of noise in the LOTC as liquidity providers may widen their spreads due to increased information asymmetry, or liquidity in general decreasing around the fixing.

The effect of macroeconomic announcements on price discovery is mixed, both in terms of significance and direction. Arguably, the most important announcement in our sample is the USGDP announcement, which is reflected in the significance and size of the coefficients for this variable (when *CS* and *ILS* are dependent variables). The negative coefficient with *CS* as the dependent variable suggests a decrease in the relative noise of futures market quotes around US GDP announcements, while the positive coefficient with *ILS* as the dependent variable indicates that around US GDP announcements, the US futures market takes on an even more important role in gold price discovery.

Similar to the USGDP result, with *CS* as the dependent variable, the coefficient for USEMPLOY is large, negative and highly significant, indicating a decrease in noise in the futures market. The last result of note in Table 4 is the UKCPI variable. The increases in futures market *IS* and *CS* are both large and highly significant (with no corresponding increase in *ILS*), indicating UK CPI announcements tend to be associated with a relative increase in futures market noise or a relative decrease in spot market noise.

5.4 Robustness tests

In this section we assess the robustness of our results. We test the robustness of our choice of lag length as well as different forms of dependent and independent variables used in our regressions. Overall the results are qualitative unchanged in the robustness tests and do not change our overall conclusions.

In our baseline models we use 200 lags in our VECM as this should be sufficient to allow markets to reach equilibrium after a price change in one market. This original method assumes that all information entering one market is disseminated to the other market within three minutes and twenty seconds. The decision to use 200 lags is arbitrary, so for robustness we use the Akaike Information Criterion (AIC) to select the optimal lag structure. We estimate a VECM with various lag lengths and compare the AIC across individual days and hours for a small randomly selected group of days. Taking the median suggests that 460 lags is the optimal lag length. We re-estimate all of our results using 460 lags in the VECM. As an illustration of the impact of this change, Table 5 reports the re-estimated regressions.

< Insert Table 5 here >

Overall the conclusions do not change with the increased lag length, with the exception of the coefficient for *ILS* on AFTERMCHANGE. All other results are similar in sign and significance. This minor inconsistency compared to our baseline results reinforces the conclusion that the COMEX platform upgrade did not have a large impact on the futures market's contribution to impounding new information.

Many macroeconomic announcements align with analyst expectations and thus do not result in much, if any, surprise. To test whether unexpected announcements have a different effect to announcements in general, we re-estimate the Table 4 regressions using announcement surprise instead of simple announcement times. In this case our dummy variable is equal to one if the news is contrary to analyst expectations as measured by the Bloomberg Analyst Survey. We find that our original results are robust to this specification.[5]

The final robustness test that we conduct is with the dependent variables. Instead of using the level of price discovery, we use the change in price discovery over the previous hour. This addresses concerns about the stationarity of the price discovery shares. We find that results are similar to our original specification.

[5] For conciseness these results are not reported, but are available from the authors upon request.

Overall our results are robust to lag lengths, whether the outcome of an announcement is surprise, and specification of the dependent variable.

6. Conclusion

This paper investigates the source of price discovery in the global gold market using a long time series sample covering the two largest markets for gold. This market is of great interest to both researchers and industry due to its immense size and economic importance. Our results provide insights into the effect that a major microstructural change and other factors can have on price leadership between markets.

Our sample covers the two largest gold markets, the New York Mercantile Exchange (COMEX) and the London over-the-counter (LOTC) market for the period 1997 to 2014. We use intraday data to calculate the Information Share, the Component Share and the Information Leadership Share. These measures have been well explored in prior literature and continue to be the main methodology in determining which markets lead price discovery.

Overall, the COMEX futures market leads in price discovery according to all the metrics we estimate. We show that a shift to a faster and more liquid market structure does not necessarily cause a greater contribution to price discovery. The move by COMEX from an open outcry system to the fully electronic GLOBEX platform increased the price discovery share of COMEX; however this increase is mainly due to the decrease in microstructural noise.

Furthermore, we estimate intraday price discovery shares and variation in the contribution of the two markets throughout the day. We find that prior to 2006 there is a significant increase in price discovery contribution aligned with COMEX floor trading hours, indicating that floor trading is an effective means of determining an efficient trade price. After 2006, variation in intraday price discovery shares greatly diminishes.

Using our intraday price discovery estimates we find that different macroeconomic announcements are absorbed differently into gold markets. There is weak evidence that the PM gold fixing increases the price discovery share contribution of LOTC, with the AM gold fixing having no such effect. There is evidence of US GDP and PPI announcements causing an increase in the price discovery of COMEX, whereas US employment announcements including Non-Farm Payroll produce an increase in market noise with no increase in price discovery share for either market. UK announcements in general have no effect on price discovery, with some causing an increase in noise in LOTC.

This research has wide impacts for the trading of gold and other instruments. Our paper shows that the change from a relatively slow open outcry system, to a fast electronic system with incentives for international trade greatly decreases microstructural noise. After the change to GLOBEX, COMEX experienced radically reduced spreads and increased trade volume, which is attributed to the low trading costs available in this market.

There are many avenues left open for future research. Markets have had and are still implementing new microstructural changes, allowing research into the effects of these changes and their effects on the efficiency of markets. COMEX has become the largest market for many other instruments, and the effect of this on other markets may be different due to the specific properties of those instruments. The mining of gold is not significant compared to holdings, meaning that gold is more decentralized than many other commodities that are consumed. Furthermore, this market allows for the research into centralized markets. Although many markets are becoming more decentralized, the opposite is happening to this market.

It will be interesting to see whether the conclusion of the COMEX International Incentive Program on December 31, 2015 will have any effect on the price discovery shares for the gold market. This program provided lower cost trading to traders outside the US. This increase in trading cost for one market is left to future study.

APPENDIX A: Calculation of Component Shares (*CS*) and Information Shares (*IS*)

We estimate the *IS* and *CS* metrics using the error correction parameters and variance-covariance of the error terms from equation (1) and (2) as in Baillie et al. (2002). The component shares are obtained from the normalized orthogonal to the vector of error correction coefficients, $\alpha_{\perp} = (\gamma_1, \gamma_2)'$, thus:

$$CS_1 = \gamma_1 = \frac{\alpha_2}{\alpha_2 - \alpha_1}, \quad CS_2 = \gamma_2 = \frac{\alpha_1}{\alpha_1 - \alpha_2} \tag{A.1}$$

Given the covariance matrix of the reduced form VECM error terms,

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

and its Cholesky factorization, $\Omega = MM'$, where

$$\mathrm{M} = \begin{pmatrix} m_{11} & 0 \\ m_{12} & m_{22} \end{pmatrix} = \begin{pmatrix} \sigma_1 & 0 \\ \rho\sigma_2 & \sigma_2(1-\rho^2)^{1/2} \end{pmatrix}, \tag{A.3}$$

we calculate the *IS* using:

$$IS_1 = \frac{(\gamma_1 m_{11} + \gamma_2 m_{12})^2}{(\gamma_1 m_{11} + \gamma_2 m_{12})^2 + (\gamma_2 m_{22})^2}, \quad IS_2 = \frac{(\gamma_2 m_{22})^2}{(\gamma_1 m_{11} + \gamma_2 m_{12})^2 + (\gamma_2 m_{22})^2}. \tag{A.4}$$

Because *IS* is impacted by the order of the price series in the Cholesky factorization, we calculate *IS* under each of the potential orderings and take the simple average, as advocated by Baillie et al. (2002).

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Table 1

Most liquid gold futures contracts

Month of year	Expiry month
January[#]	February
February	April
March[#]	April
April	June
May[#]	June
June	August
July[#]	August
August	December
September	December
October	December
November[#]	December
December	February

Note. This table illustrates the most actively traded gold futures contracts on COMEX in each month of the year. Month of year is the calendar month of any respective trading day. Expiry month indicates the most actively traded futures contract expiry month for each calendar month. [#] Volume shifts to next contract expiry month on the last two business days of this month.

Table 2

Global gold turnover during 2011

	'000 Ounces	Share of total (%)
United Kingdom	43,775,704	86.75%
United States	4,991,604	9.89%
China	697,002	1.38%
India	494,547	0.98%
Japan	488,502	0.97%
Dubai	12,507	0.02%
Total Volume	50,459,866	

Note. This table illustrates the estimated trading volume and proportion of volume traded in each of the six major gold trading countries for all gold-related instruments, including spot and derivatives. UK data are from Murray (2011), all other data are from GFMS Ltd. (2012). This table is originally compiled by Lucey et al. (2013).

Table 3

Futures market share of gold price discovery by year

Year	*IS*	*CS*	*ILS*
1997	0.6704	0.6079	0.6605
1998	0.6916	0.6020	0.7025
1999	0.7495	0.6490	0.7478
2000	0.7339	0.6841	0.6748
2001	0.7241	0.6461	0.7125
2002	0.7913	0.6444	0.8184
2003	0.8727	0.7093	0.8993
2004	0.8724	0.7288	0.8572
2005	0.8859	0.7288	0.8949
2006	0.8239	0.6543	0.8558
2007	0.9618	0.8749	0.8558
2008	0.9725	0.9238	0.7825
2009	0.9694	0.9287	0.7612
2010	0.9444	0.9208	0.6751
2011	0.9777	0.9441	0.8275
2012	0.9871	0.9552	0.7825
2013	0.9740	0.9241	0.7110
2014	0.9400	0.8915	0.7410

Note. This table reports annual averages of daily gold price discovery shares (estimated form one-second intraday observations) for the New York (COMEX) futures market. The futures market price discovery shares, which are estimated relative to the London spot market, are: Information Shares (*IS*), Component Shares (*CS*), and Information Leadership Shares (*ILS*).

Table 4
Regressions of hourly futures market gold price discovery shares

	CS	*IS*	*ILS*
	Estimate	Estimate	Estimate
AFTERMCHANGE	0.19***	0.22***	0.03***
	(99.02)	(114.50)	(10.40)
ASIA	0.01*	-0.01*	-0.01**
	(1.96)	(-1.82)	(-2.40)
USA	0.09***	0.12***	0.05***
	(27.72)	(37.78)	(9.90)
UK	0.02***	0.04***	0.04***
	(7.18)	(17.07)	(11.05)
AMFIX	0.01	0.00	-0.01*
	(1.39)	(-1.00)	(-1.89)
PMFIX	0.03***	0.03***	-0.01
	(6.10)	(7.87)	(-0.66)
UKBANKRATE	-0.01	-0.01	-0.01
	(-0.37)	(-0.50)	(-0.39)
USBANKRATE	-0.05	-0.06**	-0.02
	(-1.61)	(-2.03)	(-0.56)
UKEMPLOY	-0.04*	-0.05**	-0.01
	(-1.87)	(-2.54)	(-0.46)
USEMPLOY	-0.07***	-0.03	0.03
	(-2.66)	(-1.32)	(0.82)
UKGDP	0.00	-0.01	0.00
	(-0.18)	(-0.42)	(-0.05)
USGDP	-0.09***	-0.03	0.09***
	(-4.11)	(-1.27)	(3.05)
UKPPI	-0.04*	-0.03*	0.00
	(-1.89)	(-1.67)	(0.07)
USPPI	-0.03	0.00	0.06**
	(-1.63)	(0.09)	(2.05)
UKCPI	0.08***	0.07***	-0.02
	(4.60)	(3.88)	(-0.55)
USCPI	-0.03	0.00	0.03
	(-1.40)	(0.03)	(1.04)
INTERCEPT	0.62***	0.59***	0.46***
	(186.59)	(180.70)	(103.06)

Note. This table reports regression results in which the dependent variables are hourly futures market gold price discovery shares (Component Share, *CS*; Information Share, *IS*; Information Leadership Share, *ILS*). AFTERMCHANGE is a dummy variable that takes the value of one after COMEX switches to the GLOBEX platform. ASIA, USA, and UK are dummy variables equal to one when the Hong Kong Stock Exchange, New York Stock Exchange and London Stock Exchange are trading, respectively. AMFIX and PMFIX are dummy variables equal to one in the hour that the London gold fixing occurs. UKBANKRATE and USBANKRATE are dummy variables equal to one in the hour that the UK and US central banks announce a new target interest rate, respectively. UKEMPLOY and USEMPLOY are dummy variables equal to one in the hour that the UK and US governments announce employment figures, respectively. UKGDP and USGDP are dummy variables equal to one in the hour that the UK and US governments announce GDP figures, respectively. UKPPI and USPPI are dummy variables equal to one in the hour that the UK and US governments announce PPI figures, respectively. UKCPI and USCPI are dummy variables equal to one in the hour that the UK and US governments announce CPI figures, respectively. *t*-statistics using Newey-West standard errors are reported in parentheses. ***, ** and * denote statistical significance at 1%, 5% and 10% level, respectively.

Table 5

Regressions of hourly futures market gold price discovery shares with 460 lags

	CS	*IS*	*ILS*
	Estimate	Estimate	Estimate
AFTERMCHANGE	0.15*** (60.26)	0.13*** (59.80)	-0.03*** (-9.28)
ASIA	0.04*** (11.34)	0.01*** (3.91)	-0.03*** (-7.47)
USA	0.06*** (14.94)	0.10*** (26.40)	0.03*** (6.45)
UK	0.04*** (11.10)	0.04*** (13.98)	0.01*** (2.92)
AMFIX	0.03*** (4.27)	0.01 (1.62)	-0.02*** (-3.24)
PMFIX	0.02*** (3.31)	0.01*** (2.77)	0.00 (0.24)
UKBANKRATE	-0.01 (-0.20)	0.00 (-0.09)	-0.01 (-0.26)
USBANKRATE	0.02 (0.67)	-0.04 (-1.40)	-0.06 (-1.48)
UKEMPLOY	-0.03 (-1.37)	-0.04* (-1.83)	0.02 (0.63)
USEMPLOY	-0.07** (-2.42)	0.00 (-0.03)	0.06* (1.8)
UKGDP	-0.01 (-0.35)	-0.01 (-0.39)	0.02 (0.61)
USGDP	-0.07*** (-2.69)	0.00 (-0.09)	0.06** (1.97)
UKPPI	-0.03 (-1.30)	-0.03 (-1.38)	-0.02 (-0.61)
USPPI	-0.05* (-1.85)	-0.01 (-0.30)	0.04 (1.19)
UKCPI	0.08*** (3.14)	0.08*** (3.44)	-0.03 (-0.96)
USCPI	-0.05** (-2.03)	-0.02 (-1.02)	0.02 (0.65)
INTERCEPT	0.55*** (135.36)	0.54*** (145.17)	0.48*** (102.38)

Note. This table reports regression results in which the dependent variables are hourly futures market gold price discovery shares (Component Share, *CS*; Information Share, *IS*; Information Leadership Share, *ILS*). In contrast to Table 4, the price discovery metrics here are estimated using 460 lags of one-second intervals as suggested by AIC. AFTERMCHANGE is a dummy variable that takes the value of one after COMEX switches to the GLOBEX platform. ASIA, USA, and UK are dummy variables equal to one when the Hong Kong Stock Exchange, New York Stock Exchange and London Stock Exchange are trading, respectively. AMFIX and PMFIX are dummy variables equal to one in the hour that the London gold fixing occurs. UKBANKRATE and USBANKRATE are dummy variables equal to one in the hour that the UK and US central banks announce a new target interest rate, respectively. UKEMPLOY and USEMPLOY are dummy variables equal to one in the hour that the UK and US governments announce employment figures, respectively. UKGDP and USGDP are dummy variables equal to one in the hour that the UK and US governments announce GDP figures, respectively. UKPPI and USPPI are dummy variables equal to one in the hour that the UK and US governments announce PPI figures, respectively. UKCPI and USCPI are dummy variables equal to one in the hour that the UK and US governments announce CPI figures, respectively. *t*-statistics using Newey-West standard errors are reported in parentheses. ***, ** and * denote statistical significance at 1%, 5% and 10% level, respectively.

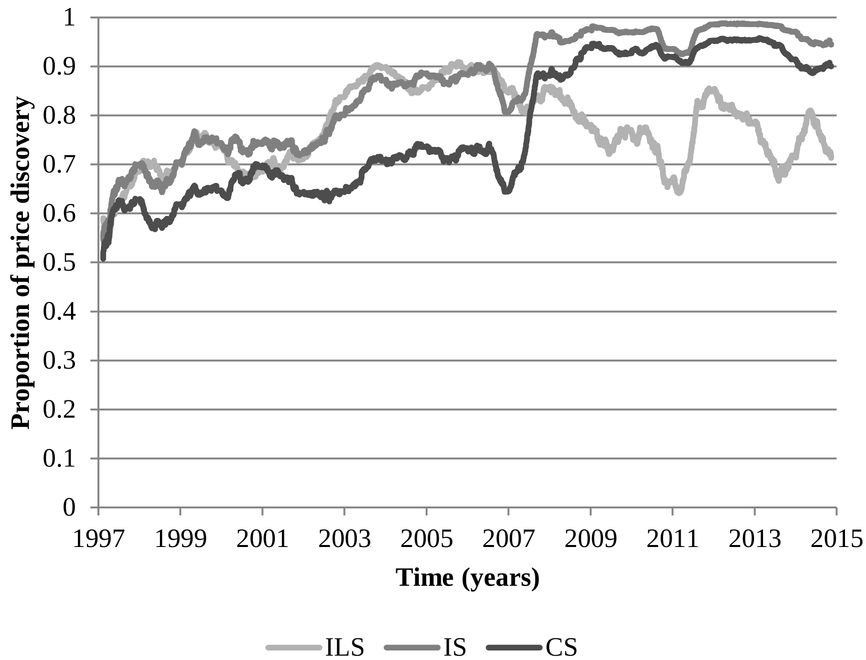

Figure 1

Futures market price discovery shares through time

Note. This figure plots the futures market (COMEX) price discovery shares through time. Each line is a 180-day moving average of the daily price discovery estimates. The daily estimates of Information Shares (*IS*), Component Shares (*CS*), and Information Leadership Shares (*ILS*) are calculated using intraday data with a sampling frequency of one second.

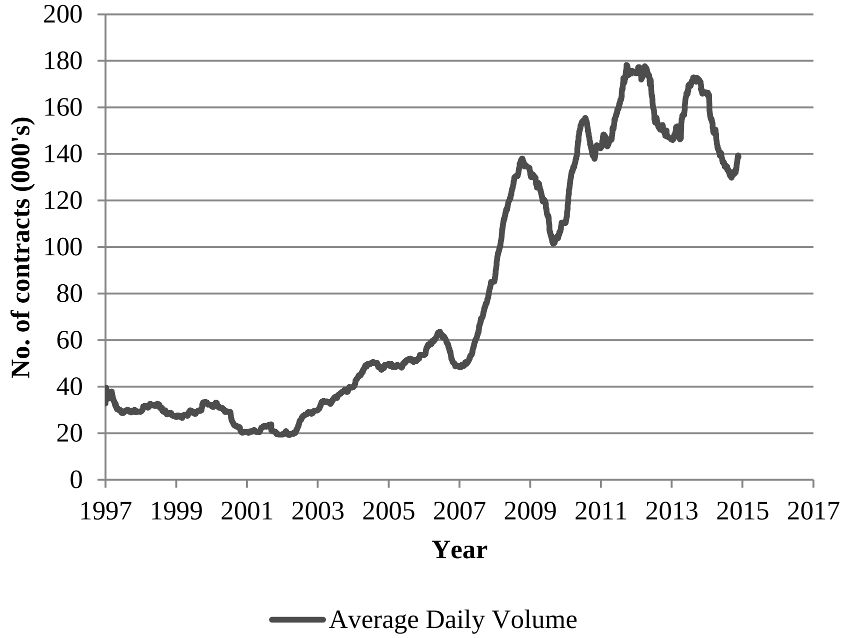

Figure 2
Futures market volume through time

Note. This figure plots the traded volume of gold futures contracts (the most active contract at every point in time, as specified in Table 1) through time. The line is a 180-day moving average of daily traded volume.

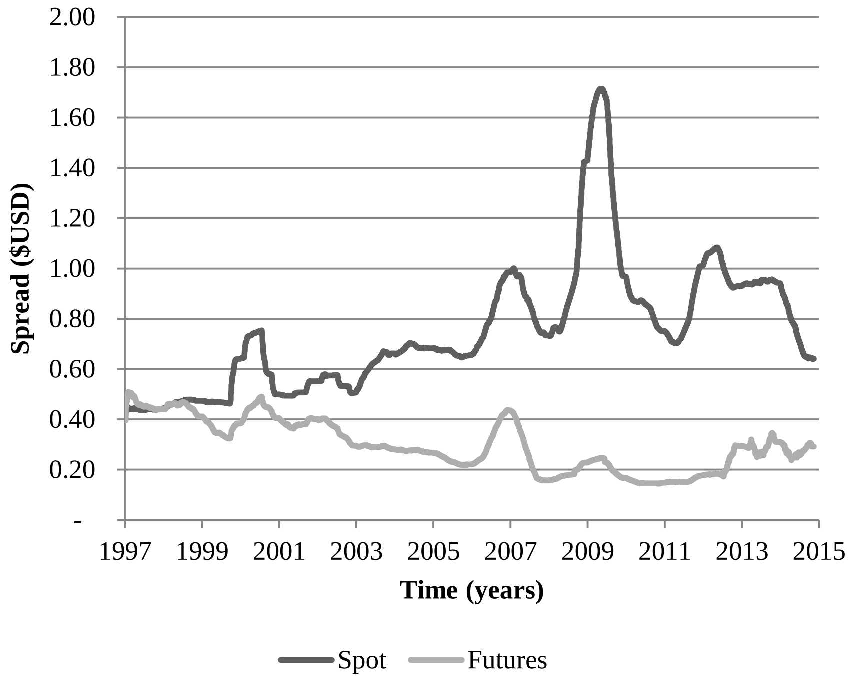

Figure 3

Bid-ask spreads through time

Note. This figure plots the 180-day moving average bid-ask spread of the London OTC gold spot quotes and the New York COMEX gold futures quotes. Each quote is for one fine troy ounce and is measured in US Dollars.

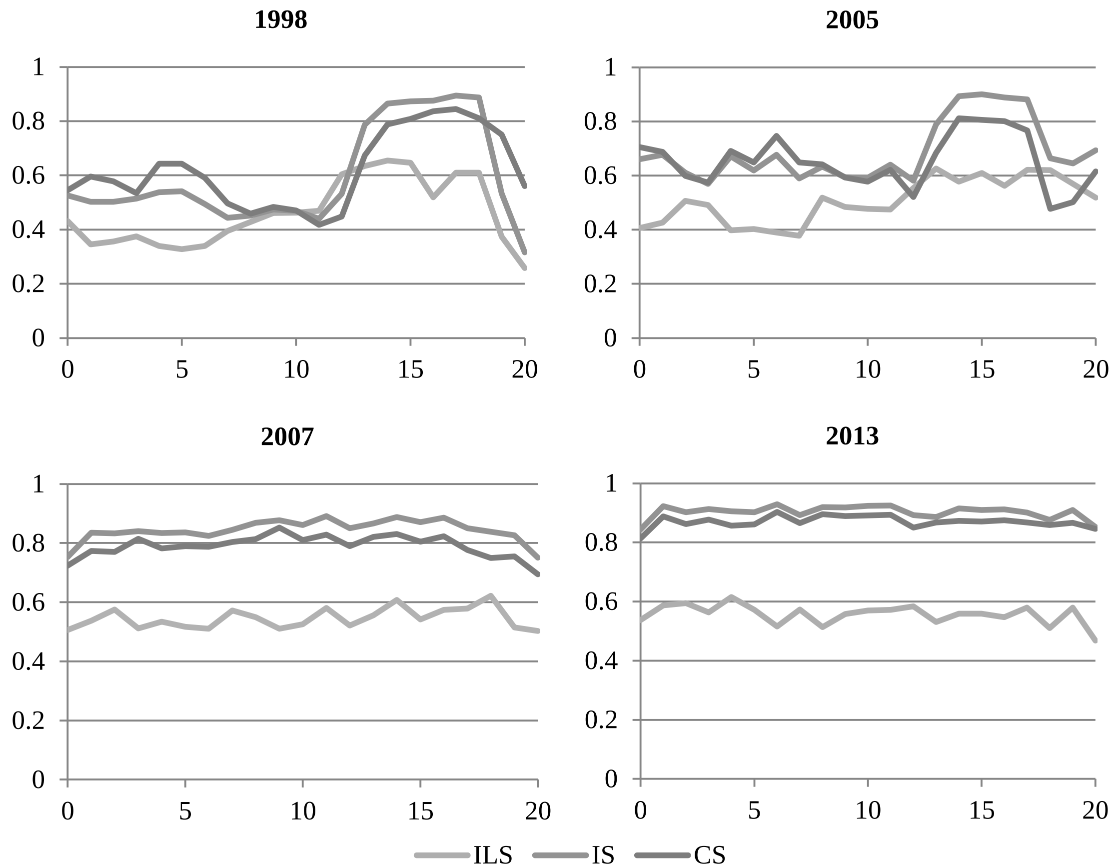

Figure 4

Intraday patterns in futures market gold price discovery shares

Note. This figure plots the futures market (COMEX) gold price discovery share intraday averages for four indicative years. Each line represents an average of the hourly price discovery estimates (Information Shares (*IS*), Component Shares (*CS*), and Information Leadership Shares (*ILS*)), which are estimated using intraday data sampled at a one-second frequency. The title of each graph is the year during which the intraday averages are estimated and the horizontal axis measures intraday time in GMT.