Any Silver Linings?
The London Silver Fixings' impact on public silver markets before and after the introduction of contemporaneous futures trading.

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Abstract:

Since 1897 the London Silver Fixing has conducted a daily auction which, to this day, sets the daily benchmark price for the precious metal. This private pricing club functions alongside active public markets for silver, including the physical spot and futures markets. This empirical market microstructure study analyses publicly traded silver instruments to assess the impact the fixing has on public markets. The study spans fourteen years of fixings, from January 2000 to December 2013, which includes the introduction of contemporaneous silver futures trading in late 2006. It finds statistically significantly lower prices around the time of the fixing in both spot and futures markets, elevated levels of trade volume and price volatility immediately following the fixing's start, well before the conclusion of the fixing and the publication of its outcome. Further, it finds statistically significant return advantages in the four minutes following the start of the fixing for informed traders while no significant returns follow the publication of the fixing outcome. Trades in the opening minutes of the fixing are highly predictive of the price direction of the fixings. The size and significance of these results increase after the introduction of contemporaneous futures trading.

JEL Codes: G14

Key words: London silver price fixing, silver futures (SI), spot silver (XAG), financial benchmarks, and precious metals.

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1 INTRODUCTION

"Now, if you can't trust a fix, what can you trust?
For a good return, you gotta go bettin' on chance,
and then you're back with anarchy. Right back in the jungle."
Johnny Caspar, Miller's Crossing (1990)

The global precious metals market consists of large, opaque and complex over-the-counter (OTC) markets operating alongside active, transparent, exchange-based derivative markets. These markets trade the physical commodity as well as a wide variety of derivatives including futures, exchange trades funds, options and volatility instruments. They span the globe and trade virtually round the clock. Participants include producers (miners and refiners), consumers (jewelers and industrials), sovereign reserve banks and a deep bench of intermediaries ranging from the world's largest banks, to commodity trading houses, high frequency traders and speculators. Amongst this cacophony of trading, a relatively calm ritual takes place each day known as the London silver 'fixing'.

The 'fixing', a private auction amongst a select group of precious metal dealers, sets the official daily benchmark price for precious metals. Four precious metals (Gold, Silver, Platinum and Palladium) use this price discovery mechanism, with only slight variations from metal to metal. The oldest of these fixings is the silver fixing, dating its origin to 1897 with the "official start of the London Silver Fixing in the offices of Sharps & Wilkins, with Mocatta & Goldsmid, Pixley & Abell, and Samuel Montagu in attendance".[1]

While names have changed, and the number of members has reduced, to this day fixing members meet at noon in London and set the benchmark mark price for silver. For a market institution to survive 116 years is no trivial feat. In the case of the silver fixing, it is

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[1] The London Silver Fixing Ltd. website (https://www.silverfixing.com/silver-fixing-history)

even more impressive given it has seen the rise and demise of metalism or 'monetary metal',
two world wars, the collapse of several currency accords, the advent of global derivative
markets and even the rise of high frequency trading.

The current wave of regulatory scrutiny of financial benchmarks, however, may
prove to be the silver fixing's toughest challenge yet. Present-day suspicion of financial
benchmarks is not without basis. The recent London Interbank Offer Rate (LIBOR) and
ISDAfix currency exchange scandals[2] have revealed manipulation of the most widely used
financial benchmarks. For the offending banks, the consequences of these market abuses have
run into the hundreds of millions of dollars of fines[3] and unquantifiable brand damage. Not
unreasonably, the public trust in financial benchmarks has fallen, and regulators are now
conducting active reviews into all benchmarks, including precious metal fixings.[4]

The LIBOR scandal demonstrates that participants in a benchmark fixing club can
and do manipulate market prices. While manipulation of prices has attracted much public
attention in the LIBOR debacle, there is another feature of this market structure that deserves
particular consideration. Being privy to the proceedings of a fixing could give the fixing
participants access to price-sensitive market information such as price direction. Should the
fixing participants trade in public markets during the fixing period and prior the release of the
fixing result, they may be receiving a profitable trade advantage over public market
participants.

It is against this backdrop that this study seeks to explore the interactions between the
private silver fixing and the public silver markets. While some literature suggests that the
physical metals markets are reasonably efficient, there has been little published on the
interaction of the silver fixings and public markets. This paper addresses this gap in the
literature by focusing on two key questions. First, does the London silver fixing (still) have an

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[2] http://www.businessweek.com/articles/2013-04-18/meet-isdafix-the-libor-scandals-sequel
[3] http://en.wikipedia.org/wiki/Libor_scandal
[4] http://www.reuters.com/article/2014/01/17/deutsche-gold-fix-idUSL5N0KR19G20140117

impact on public silver markets? Second, are fixing participants granted an economic trade advantage over the broad market?

This study takes an empirical market microstructure approach, analyzing tick-for-tick quotes and trades of the CME Group's COMEX silver future contracts (SI) and the 'spot' physical silver (XAG). These are the dominant silver markets in terms of trade activity. The analysis follows that of other event studies, in particular the intraday event studies as put forward in Ederington and Lee (1995), and later adapted to the analysis of the gold fixing by Caminschi and Heaney (2013). The sample data spans fourteen years, from January 2000 through to December 2013.

Broadly, there are five key findings:

a. The London fixing has an impact on public silver markets. This study finds a 10-12 bps downward bias in the intraday price of silver around the time of the fixing. The short term price dip represents three times the average *daily* return on silver over the same period. This is illustrated in Figure 1, and its statistical significance is confirmed in Figure 2. A detailed description of this, and other key events impacting the public silver markets during the London trade day, can be found at Section 4.1 of the results.

b. There is strong empirical evidence the price behavior of the fixings is significantly different to that of open market instruments (spot and silver futures) trading at the same time. Specifically, the fixing price seems to be consistently lower than the (already suppressed) open market prices. Returns across the fixing are negative twice as often as positive, and the magnitudes of negative returns are significantly larger than the magnitudes of positive returns. This yields a further average discount of 6 bps to public market prices. This is detailed at section 4.2 which focuses on characterizing the silver fixing period and returns.

c. The timing of market reactions to the fixing, as witnessed by increases in trade volume and price volatility, align to the *start* of the fixing. Most of the market

reaction takes place in the opening two minutes of the fixing, and well before its conclusion. The subsequent publication of the fixing result shows little or no impact on these measures of market activity. This extends the findings for the London PM gold fixing presented in Caminschi and Heaney (2013), and is detailed at Section 4.3.

d. Market participants with prior knowledge of price direction have a daily average advantage of 25 bps over uninformed traders. Further, price movements in the open market instruments are highly predictive of the ultimate price direction implied by the fixing result. This suggests that profitable front running during the fixing period is indeed taking place.

e. The introduction of contemporaneous silver futures trading in late 2006 had profound impacts on all the above-mentioned results. The increased tradability of silver at the time of the fixing amplified the size and significance of these results.

These findings should be of concern to any market participant that has traded in silver, or its derivatives, around the time of the fixings, or has been party to contracts benchmarked to the silver fixing. It further brings into question the status of the silver fixing as an essential institution in the global silver trade.

The remainder of the paper is organized as follows: background information is presented at Section 2, the sample data and analysis methods are detailed at Section 3, and the results of the analysis are presented at Section 4. Section 5 concludes with a discussion of arguments put forward explain these findings, consequences of these findings, and a brief outline of alternatives to the current benchmark.

2   BACKGROUND & RELEVANT LITERATURE

2.1   THE LONDON SILVER FIXING

The origin of the London silver fixing (herein referred to as "the fixing") dates back to 1897, when the four silver dealers would meet each day (1.45 pm on weekdays and 11.45 am on Saturdays) to settle on the daily silver price. The original members comprised Sharps & Wilkins, Mocatta & Goldsmid, Pixley & Abell, and Samuel Montagu, the four leading precious metal dealers of their day.

Over a hundred years later, the fixing has changed only slightly. Sharps & Wilkins merged with Pixley & Abell to become Sharps & Pixely, which was then bought by Deutsche Bank. Scotiabank bought Mocatta & Goldsmid, while HSBC bought Montagu. In 1999, the physical meetings were replaced with a teleconference, and the time was moved to noon each London business day. This structure remains in place to the present day[5] and is administered by London Silver Market Fixing Ltd. (www.silverfixing.com). The chair of the fix is rotated through the membership, with the current chair being Scotiabank.

The fixing process is a 'Walrasian' auction for wholesale physical silver. All participants, including the member's clients, funnel their orders through the three fixing members. Clients range broadly: silver producers (miners, refiners), silver consumers (jewelers, industrials), investors, speculators and private individuals to sovereign states. Fixing members consolidate their respective client orders, as well as any orders from their own proprietary trade desks.

The fixing process begins with the Chair announcing a starting price, which is usually near the current spot price. Each of the remaining members then declares themselves as either a net buyer or a net seller at this price. The Chair then adjusts the price until there are both

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[5] At the time of writing it had been reported that Deutsche Bank was seeking to sell or retire from both the silver and gold fixings. However, this change is yet to be implemented.
http://www.reuters.com/article/2014/04/25/gold-fix-seat-sale-idUSL6N0N62J620140425

buyers and sellers declared. The auction progresses to the next phase with buyers and sellers declaring the quantity they seek to transact at this price. The Chair then adjusts the price to bring the quantities to balance. With quantities balanced, to within 50 bars[6], the Chair deems the price to be "fixed" and announces the result to the LBMA for broad publication. The process typically lasts two to ten minutes, depending on the trade conditions of the day. During the proceedings, fixing members are not restricted in trading in other silver related instruments.

It must be emphasized that while there are only three fixing members, the fixing participants include the clients of these members. While the clients are not privy to the fixing's teleconference, there are no rules preventing clients from receiving updates during the fixing. Further, clients have some insight into the composition of the order book even if only from their own order. This is especially true if the client is bringing a large order to the fixing.

2.2   PHYSICAL SPOT SILVER

London is the center of the global bullion market, with its origins and leadership tracing back to the 17th century. Its present structure, however, was largely created in the 1980's. The Bank of England originally regulated the market until 2000, when market oversight was transferred to the Financial Services Authority (FSA), in consultation with the London Bullion Market Association (LBMA). With the dissolution of the FSA in 2012, regulatory oversight reverted to the Bank of England.

The silver bullion market is an OTC market with no central exchange. The market consists of the 11 market-maker members of the LMBA[7], which includes the current three fixing members. While market makers are required to provide two quotes during regular

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[6] A 'bar' being specified as approximately 1000 troy ounces of 99.9% purity silver. See http://www.lbma.org.uk/good-delivery-rules for further details, including tolerances.
[7] The full list of members is available at http://www.lbma.org.uk/membership

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London business hours, 8am to 5pm, the market functions virtually around the clock with regional offices providing coverage.

Market data on spot silver consists of the two way quotes (bids and asks) provided by these market makers, with no records of actual trades being publicly available. Financial market data providers, such as Bloomberg or Thompson-Reuters, commonly consolidate the quotes from several sources, and report the consolidated feed under the generic ticker "XAG". Prices for spot silver are quoted in US Dollar per troy ounce, and spot settlement is "T+2", i.e. delivery and payment must clear on the 2nd business day after the trade.

2.3 SILVER FUTURES

There are a wide range of futures exchanges trading gold futures contracts, including the Tokyo Commodity Exchange (TOCOM), and more recently the Multi Commodity Exchange (MCX) in Mumbai and the Shanghai Futures Exchange (SHFE). However, it is the CME Group's COMEX, based in New York, which remains the dominant futures market for precious metals, including silver.

The COMEX silver futures contract, ticker "SI", covers 5000 troy ounces of good delivery silver, physically settled at a CME certified warehouse within the contract delivery month. This contract is quoted in US Dollars with a tick size (minimum price fluctuations) of USD 0.005 (half a cent per troy ounce). The contract trades on three platforms within the CME group: the electronic CME Globex, the CME Clearport for block trades, and the original COMEX open outcry pit in New York. The Globex platform has come to dominate the open outcry pit, as outlined by Karan *et al.* (2008), and thus Globex market data are used in the analysis.

Maturities for the SI contract range from the current month to 60 months out. That said, trade activity centers on the nearest designated "active" month contract. These are: March,

May, July, September and December. While multiple contracts can open on any give trade day, this study only analyses pricing data of the active month contract.

Market data on silver futures is relatively rich. Trade and quotes data are provided by the exchange for public record. This includes records of all transactions with price and volume data which, unlike the OTC markets, gives us direct measurement of market activity.

Transaction costs for these futures contracts are low. For CME futures there are three components to transaction costs: exchange fees, brokerage commissions and regulatory fees. The CME/COMEX exchange fees for the SI contract range from USD 0.45 to USD 1.45 per contract, with brokerage fees adding a further USD 0.25 per contract or more.[8] Total trading fees range from USD 0.70 per contract for high volume institutional traders to USD 2.32/contract for retail traders. As one contract covers 5000 oz. of silver, with each ounce having a price of $20, this results in a notional exposure of $100,000. Even for the worst case of $2.32 per contract for retail traders, the transaction costs represent less than 0.0023% or 0.23 basis points (bps) of notional value. Apart from the explicit transaction costs, other key trade costs are traversing the bid-ask spread and slippage. While these costs are difficult to estimate, each price tick represents about 0.025% (2.5 bps) of notional value, using a price of $20 per ounce. Allowing for four ticks of slippage and spread, and two sets of transaction costs, a threshold of 10 bps will be used classify a round-trip trade as economic.

2.4   RESEARCH QUESTIONS

Previous literature has focused on the determinants of precious metal prices, market efficiency and linkages that exist between various related markets. The price determinants literature is generally based on analysis using monthly data (Abken 1980; Tschoegl 1980; Levin 2006; Aggarwal & Lucey 2007; Blose 2009; Dwyer 2011), though intra-day data has

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[8] Source: CME Website –NYMEX Fee schedule (July 2, 2012) and Interactive Brokers LLC published fee schedule (August 2012).

been used in the analysis of reactions to macroeconomic announcements (Christie–David *et al.* 2000). More finely sampled data has also been used in tests of market efficiency with both support for, and rejection of, market efficiency (Basu & Clouse 1993; Chng 2009; Narayan *et al.* 2010). Similar variation is also evident in other derivative markets, including the futures options markets, particularly with respect to put-call parity (Beckers 1984; Followill & Helms 1990) and exchange-traded fund markets (Charupat & Miu 2011). Theissen (2012) examines cross-market links and price discovery using an exchange-traded fund and a futures contract, with both securities written on the DAX share price index, and finds futures markets tends to lead the spot market. Pavabutr and Chaihetphon (2008) find the same in Indian spot and futures prices. So while there have been a number of studies that use London fixing prices, there have yet to be published studies on the London silver price fixing and its intraday effects on the broader silver market. This study addresses this gap in the literature.

The findings in Caminschi and Heaney (2013), relating to the gold fixing, provide the basis of the research questions in this study. Do we see the same evidence of a 'leaky fixing' in the silver markets as are reported for the gold markets? This underlies the two of the key research questions and associated hypotheses. First, does the London silver fixing (still) have an impact on public silver markets? Given the evidence from the gold market, the hypothesis is that the silver fixing *does* impact public silver markets. Second, can participating in the fixing grant an economic trade advantage to the fixing members? Again, based on the evidence from the gold market, the hypothesis is that the silver fixing *does* grant such an information advantage. This advantage is economic, exceeding reasonable transaction costs.

3   DATA & METHODOLOGY

3.1   OVERVIEW OF METHODOLOGY

This study draws on the intraday event study methodology originally put forward in Ederington and Lee (1995) and subsequently adapted to the analysis of the gold fixing in Caminschi and Heaney (2013). The adaptations focused on the treatment of the fixing end event. Due to variability of the fix periods, the end event does not occur at a constant time of day, unlike the fixing's start event. This paper extends the Caminschi and Heaney (2013) study by incorporating a detailed analysis of fixing periods and returns, enabled by the richer data set presently available for the silver fixing. Whereas Caminschi and Heaney (2013) were restricted in terms of access to fixing end times, this study has a complete record for the chosen study period.

3.2   SAMPLE DATA

The data analyzed in this study comprises the intraday spot silver quotes (XAG), the trade and quote data on the silver futures (SI), and the time and price data for the silver fixing (XAGFIX). All market data are obtained from the Thompson-Reuters Tick History (TRTH) database, with access provided via SIRCA[9].

The period covers fourteen years, from 1 January 2000 to 31 December 2013, and captures the current structure of the silver fixing. Specifically it excludes structural changes that occurred in 1999. The period is also neatly divided in two, almost equal, sub-periods by the NYMEX/COMEX introduction of electronic trading in December 2006. Apart from moving trade activity from the physical COMEX trade floor, it also expanded the contract's trading hours to overlap the silver fixing.

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[9] http://www.sirca.org.au/

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Over the study period there were a total of 3,519 fixings for which there are 4,420 records, including updates and final results. These are filtered to remove fixings on days with no futures market data, no spot market data, fixing with periods exceeding one hour and negative fixing periods. Table 1 below details the impact on the sample of each of these exceptions, with the largest sample reduction coming from missing futures data, caused by the mismatch in US and UK holidays.

<< **TABLE 1 – Sample data issues impact summary** roughly here >>

Overall, however, only 141 (4%) of all the fixings are excluded from the sample. This 3,378 fixings in the final sample used in this study. Summary statistics for the final sample are reported in Table 2 below.

<< **TABLE 2 – FIXING SUMMARY STATS** roughly here >>

3.3 ANALYSIS WINDOWS, INTERVALS, REFERENCE TIME AND TIME ALIGNMENT

This study uses two intraday windows for analysis. The first is a broad window covering ten hours of the London business day, from 9am to 7pm. This is wide enough to capture key trade day events in London and New York to provide an overall context for silver market dynamics. The second window is narrower, focusing on a two-hour window centered on the silver fixing. This added timing resolution allows us to discriminate market events as being aligned to the start or the end of the fixing.

The narrow time analysis window is centered on either the start or end of the fixing to allow separate analysis of these periods. The analysis window and its key components is illustrated in Figure 1.

<< INSERT FIGURE 1 AROUND ABOUT HERE >>

The start-aligned analysis window, depicted in Figure 1, Panel A, is centered on the fixing start, at time t_o = 12:00 noon. One-minute intervals are denoted $\mathbf{i}$ = -59 to +60, with interval closing time t_i ranging from 10:01 through to 13:00. The last interval before the start of the fixing is $\mathbf{i=0}$, with t_i= 12:00 noon (London). The interval reference convention used in this study identifies intervals by their close time, with closing time being exclusionary. For example, the "12:00" one-minute interval ($\mathbf{i}$=0, t_i=12:00) covers data from 11:59am (inclusive) to noon (exclusive): it includes data time stamped 11:59am and excludes data time stamped 12:00pm.

For end-aligned windows, depicted in Figure 1, Panel B, $\mathbf{i=0}$ is the last interval before the end of the fixing. Similarly, one-minute intervals are denoted $\mathbf{i}$ = -59 to +60. However, these intervals do not map to a specific time of day, as the end of fixing does not occur on a preset time of day, unlike the fixing start.

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In comparing volume and volatility levels a reference period of fifteen minutes is used. In the case of start-aligned windows, this reference period covers the period from 11:30am to 11:45am (London). In the case of end-aligned windows, the reference period covers intervals fifteen to thirty minutes from the end of the fix. In either case, the volume/volatility over the reference period is averaged to determine the reference level of volume/volatility. The offset and length of this reference window were chosen to provide a stable benchmark. The results presented are robust to choice of offset and length. Similar results were obtained ranging the offset from 10 to 60 minutes and length from 5 to 45 minutes.

All timestamps are referenced to British Standard Time (BST), i.e. UTC/GMT with summer daylight saving adjustment. XAG timestamps are converted from UTC/, while SI is adjusted from New York local time. Differences in daylight savings transition dates between the cities, typically lasting about one week, result in the usual five-hour difference shortening to four. This in turn causes the noon fixing to align to 8:00am New York local time, as opposed to the usual 7:00am.

3.4 TRADE VOLUME

Volume data are available for silver futures, unlike for spot silver and the fixing. This provides an opportunity to measure the level of trade activity in the futures market. New information arriving to a market usually triggers a short-term elevation in trade volumes as market participants adjust positions to the new information. Accordingly, the timing of any material change to relative volume can be used as an indicator of new information arriving to the market (Acker *et al.* 2002; Chae 2005).

Total volume traded in a given one-minute interval i, on a given day d is denoted as $VM_{i,d}$. For each day, a reference trade volume level ($VMref_d$) is calculated by taking the

arithmetic averaging of the trade volume in the 15 minute reference period[10]. Averaging across the days in the sample yields $\overline{VM_i}$, the average volume for interval i, and $\overline{VMref}$, the average reference volume level.

In calculating *relative* volume, we could simply divide $VM_{i,d}$ by $VMref_d$. This, however, creates two issues. First, the presence of zero volume intervals, particularly prevalent prior 2007, can create zero $VMref_d$ values. Second, the strong asymmetry of the $VM_{i,d}$ distribution, caused by volume being zero bound, results in a relative volume distribution that is heavily skewed. While large sample t-test statistics are robust to non-normality, they are affected by severe skew.

To address these issues, $logVM_{i,d}$ is defined as the natural log of $VM_{i,d}$, where any zero instances are replaced with a small non-zero value[11]. The reference level ($logVMref_d$) is calculated, as with $VMref_d$, by taking the arithmetic averaging of $logVM_{i,d}$ over the 15 minute reference period. The relative volume can then be defined as $\Delta VM_{i,d} = logVM_{i,d} - logVMref_d$. Averaging across the days in the sample yields $\overline{\Delta VM_i}$, the average *relative* volume of interval i. The log transformation normalizes and largely resolves the heavy skew caused by the zero bound on volume. Whereas the zero value substitution removes the divide by zero problem.

To test the significance of changes in trade volume, a one-sided, paired t-tests is conducted to test $\overline{VM_i} > \overline{VMref}$, using the untransformed data. While a one-tailed, paired t-test is conducted to test $\overline{\Delta VM_i} > 0$, using the transformed data.

3.5 RELATIVE VOLATILITY

Another marker for information entering a market is the increased level of price volatility. Much in the same way as for volume, relative volatility is calculated for one minute intervals on each trade day within the analysis windows. The Garman-Klass volatility estimator is used to estimate price volatility over each one minute interval in the event

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[10] The reference period is defined in Section 3.3.
[11] The value 0.1 contracts was chosen, with the key findings being robust to other values such as 0.01 through to 1.0

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window, denoted $\mathbf{V}_{i,d}$. The volatility estimate is based on open, high, low and close of mid-point quotes ($\mathbf{O}_{i,d}$, $\mathbf{H}_{i,d}$, $\mathbf{L}_{i,d}$, $\mathbf{C}_{i,d}$) for each one-minute interval, $\boldsymbol{i}$, on a given day $\boldsymbol{d}$.[12]

$$V_{i,d} = \sqrt{\frac{1}{2}\left(ln\left(\frac{H_{i,d}}{L_{i,d}}\right)\right)^2 - (2ln2 - 1)\left(ln\left(\frac{C_{i,d}}{O_{i,d}}\right)\right)^2} \tag{1}$$

For each day, a reference price volatility level ($\boldsymbol{Vref_d}$) is calculated by taking the arithmetic averaging of the price volatility in the 15 minute reference period[13]. Averaging across the days in the sample yields $\overline{V_i}$, the averaging volatility for interval $\boldsymbol{i}$, and $\overline{Vref}$, the average reference volatility level.

In calculating *relative* volume, we encounter the same issues as with relative volume, and adopt the same approach. A modified $\boldsymbol{logV_{i,d}}$ is defined as the natural log of $\boldsymbol{V_{i,d}}$, where any zero instances are replaced with a small non-zero value[14]. The reference level ($\boldsymbol{logVref_d}$) is calculated, as with $\boldsymbol{Vref_d}$, by taking the arithmetic averaging of $\boldsymbol{logV_{i,d}}$ over the 15 minute reference period. The relative volatility can then be defined as $\Delta V_{i,d} = \boldsymbol{logV_{i,d}} - \boldsymbol{logVref_d}$. Averaging across the days in the sample yields $\overline{\boldsymbol{\Delta VM_i}}$, the average *relative* volatility of interval $\boldsymbol{i}$. Again, the log transformation normalizes and largely resolves the heavy skew caused by the zero bound on volume, whereas the zero value substitution removes the divide by zero problem.

To test the significance of change to trade volume, a one-tiled, paired t-test is conducted to test $\overline{V_i} > \overline{Vref}$, using the untransformed data. A one-tailed, paired t-tests is conducted to test $\overline{\Delta V_i} > 0$, using the transformed data.

3.6 RETURNS

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[12] For robustness, the analysis was repeated using two other estimators, the Parkinson estimator and the Rogers-Satchell estimator, with no material change in results.
[13] The reference period is defined in Section 3.3.
[14] The value 1.0 bps was chosen, with the key findings being robust to other values.

Two return measures are used in the analysis: 'unadjusted return' and 'adjusted return'. They represent the returns available to 'uninformed' and 'informed' traders, respectively. The difference between these return measures, 'difference in returns' is calculated to quantify any advantage the informed trader has over the uninformed trader.

3.6.1   Unadjusted returns (UR, CUR)

The unadjusted returns are realized by holding a long position, in either SI or XAG, for one minute. Interval close prices, denoted $\mathbf{C}_{i,d}$ for the one-minute interval for i, on a given day d, are derived from the mid-point of bid and ask at the end of the interval. The unadjusted return ($\mathbf{UR}_{i,d}$) is used to calculate the average unadjusted return ($\overline{\mathbf{UR}_i}$) and cumulative unadjusted return (CUR_i) as follows:

$$UR_{i,d} = ln\left(\frac{C_{i,d}}{C_{i-1,d}}\right) \tag{2}$$

$$\overline{UR}_i = \frac{1}{N}\sum_{d=1}^{N} UR_{i,d} \tag{3}$$

$$CUR_i = \sum_{x=-59}^{i} \overline{UR_x} - \sum_{x=-59}^{0} \overline{UR_x} \tag{8}$$

The second term of the $\mathbf{CUR}_i$ is an adjustment to ensure $\mathbf{CUR}_0 = 0$, i.e. the cumulative return is zero at the event interval, be it the fixing start or the fixing end.

3.6.2   Adjusted returns (AR, CAR)

Ederington and Lee (1995) introduced the construction of 'adjusted' returns to captures return based on an informed view of future price direction. Adjusted returns are unadjusted returns "adjusted" for price direction implied by the information from the fixing event. This is the price direction implied by the new fixing price. The price direction factor is the sign of the difference between the price of spot silver immediately prior to the fixing ($XAG_{0,d}$) and the eventual published fixing price (FIX_d). When this direction is positive, the

return is calculated assuming a long position, in line with unadjusted returns. When the direction is negative, the return is calculated assuming a short position, resulting in the negative of the corresponding unadjusted return.

To realize these adjusted returns, a trader requires directional foresight of the fixing price. This foresight is limited to knowing that the final fixing price will be higher or lower relative to the pre-fixing spot price. The trader is *not* assumed to have perfect foresight of the final fixing price, just its direction. Traders with this directional foresight are referred to as 'informed'.

Realizing unadjusted returns places no requirement on the trader's ability to forecast the outcome of the price fixing; the trader can realize this return simply having an 'uninformed' long position open over the interval. Realizing adjusted returns, however, places a considerable burden on the trader. The informed trader must go long *or* short, and make this decision before the fixing price is published. The degree to which the trader has this directional foresight, and critically *when* the trader gains this foresight, will determine how much of the adjusted return they can capture.

Adjusted returns are calculated as the product of the unadjusted return and an adjustment factor (**FIXDIR$_d$**) which captures the price direction adjustment implied the sign of the fix return ($R_{Fix,d}$). The silver price immediately preceding the start of the fixing (**XAG$_{0,d}$**) and the eventual published fixing price (**FIX$_d$**) are used in derive both the fix return and fix direction for any given day **d**, as formalized below:

$$R_{Fix,d} = log\left(\frac{FIX_d - XAG_{0,d}}{XAG_{0,d}}\right) \tag{8}$$

$$FIXDIR_d = sgn\left(R_{Fix,d}\right) = \begin{cases} +1, & R_{Fix,d} > 0 \\ -1, & R_{Fix,d} < 0 \\ 0, & R_{Fix,d} = 0 \end{cases} \tag{9}$$

The adjusted return (**AR$_{i,d}$**) is then used to calculate the average adjusted return ($\overline{AR_i}$) and cumulative adjusted returns (**CAR$_i$**) as follows:

$$AR_{i,d} = \text{FIXDIR}_d \cdot ln\left(\frac{C_{i,d}}{C_{i-1,d}}\right) \tag{10}$$

$$\overline{AR_i} = \frac{1}{N}\sum_{d=1}^{N} AR_{i,d} \tag{11}$$

$$CAR_i = \sum_{x=-59}^{i} \overline{AR_x} - \sum_{x=-59}^{0} \overline{AR_x} \tag{12}$$

3.6.3   Difference in returns (DR, CDR)

With unadjusted returns defined as the return of an uninformed "long" trader, and the

adjusted returns defined as the return of an informed trader with directional foresight, the

difference between these two returns is calculated to quantify the value of the directional

foresight. The difference in returns (**DR**$_{i,d}$), the average difference in returns ($\overline{DR_i}$), and the

cumulative difference in returns (**CDR**$_i$) are defined as follows:

$$DR_{i,d} = AR_{i,d} - UR_{i,d} \tag{13}$$

$$\overline{DR_i} = \frac{1}{N}\sum_{d=1}^{N} DR_{i,d} \tag{14}$$

$$CDR_i = \sum_{x=-59}^{i} \overline{DR_x} - \sum_{x=-59}^{0} \overline{DR_x} \tag{15}$$

Another feature of the difference in returns (**DR**) is its immunity from long-term market

trends, such as the prolonged secular bull market in silver that persisted through to the later

part of 2011. By virtue of differencing, these trends are cancelled and we are left to focus on

the difference between the uninformed and informed trader.

3.7   PREDICTIVE VALUE OF MARKET RETURNS

A further test of information leakage is to assess how effective market prices are in

predicting the future price direction of fixings. Two aspects of predictability are assessed: a)

at what time, if ever, do markets prices become predictive, and b) is the predictability related

to the magnitude of the fix return (**R**$_{Fix}$). The timing of predictability is crucial to determine if

information is entering the markets *before* the fix result is public. Analyzing differences in predictability between large and small fix return days looks at the response to economic incentive for leaking information. On days with large (absolute) fix returns, the predictability offers large potential profits, which would push informed trader into the markets sooner, and in turn would lead to higher levels of prediction.

The assessment of prediction will be based on the simplest of algorithms. The price in the open market instrument is observed at two points in time, both prior to the publication of the fix result. The difference between the prices yields a market price direction (positive, negative or flat), which becomes the predicted fixing price direction. The proportion of correct predictions is denoted by *P*. The two observation are taken from the mid-point close price of a *reference* interval and a *cut-off* interval. The analysis is run for various cut-off times to determine when, if ever, the market returns show significant levels of prediction. While the cut-off time is never set past the end of the fixing, it can be set past the start of the fixing. When the cut-off time occurs after the fixing start ($i > 0$, $t_i > 12:00$), care is taken to exclude from the sample any fixings that have already concluded. As such, the sub-sample (S_i) is constructed to include only the fixings that conclude after cut-off time t_i. For each S_i, the proportion of correct predictions (P_i) is calculated, and a proportion z-test is used to test the significance of $P_i = {}^1\!/_3$, the proportion expected from randomly assigning the fixing direction.

To compare large and small fix return days, S_i is then sub-divided into $S_{i,Sml}$ and $S_{i,Lrg}$. All fixings with fix return magnitudes exceeding the median for S_i are allocated to $S_{i,Lrg}$, the others to $S_{i,Sml}$. The proportion of correct predictions within each of these two sub-samples is denoted by $P_{i,Lrg}$ and $P_{i,Sml}$. A χ^2 contingency table test is used to test $P_{i,Lrg} = P_{i,Sml}$ and report the significance of rejection is reported.

Two additional variables are defined to support this analysis: the direction of the market price movement ($\boldsymbol{MKTDIR_{i,d}}$) and a generalized version of the fix return direction ($\boldsymbol{FIXDIR_d^*}$), formally defined below:

$$RMkt_i = log(\frac{C_{i,d} - C_{Ref,d}}{C_{Ref,d}}) \, , \; C_{Ref,d} = \begin{cases} C_{0,d} & , \; i \geq 1 \\ C_{-30,d} & , \; i < 1 \end{cases} \tag{16}$$

$$MKTDIR_{i,d} = \begin{cases} -1 \, , & RMkt_i < -\Delta min \\ 0 \, , & -\Delta min \leq RMkt_i \leq \Delta min \\ +1 \, , & \Delta min < RMkt_i \end{cases} \tag{16}$$

$$FIXDIR_d^* = \begin{cases} -1 \, , & R_{Fix,d} < -\Delta min \\ 0 \, , & -\Delta min \leq R_{Fix,d} \leq \Delta min \\ +1 \, , & \Delta min < R_{Fix,d} \end{cases} \tag{17}$$

MKTDIR$_{i,d}$ is the direction of the price movement of the open market instrument, relative to a reference price $C_{REF,d}$, at the close of interval i, on a given day d, and represents the predicted direction of the fixing. Two reference prices are used: one for assessing the predictive value of market returns before the start of the fixing ($i \leq 0$), the other for market returns after the start of the fixing ($i \geq 1$). In the first case, the mid-point price at 11:30am[15] ($i = -30$) is used, whereas in the second case price immediately before the fixing start ($i=0$, t_i=12:00 noon) is used.

Both $FIXDIR_d^*$ and $MKTDIR_{i,d}$ use an additional parameter, Δmin, to discriminate between the three possible directions (positive, negative and flat). This Δmin parameter sets the materiality threshold. Returns with magnitudes smaller than Δmin are classified as "flat" regardless of their sign. This is useful as it distinguishes price movements which may exceed trading costs from those that don't. In determining P_i, $P_{i,Sml}$ and $P_{i,Lrg}$ correct predictions are deemed to occur only when $FIXDIR_d^* = MKTDIR_{i,d}$.

It should be noted this is the most simplistic predictive model, and is not intended to represent an optimized predictive algorithm. More elaborate models drawing on more granular market information such as trade sizes, limit order book dynamics, trade and quote time of arrival and such could yield significantly higher rates of prediction. As such the **P$_i$**, **P$_{Sml}$** and **P$_{Lrg}$** should be interpreted as *minimum*, not maximum, prediction levels.

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[15] The choice of reference time is not critical. Reference times from 10 to 60 minutes before the fixing were assessed with no material impacts to the results presented.

4 RESULTS

There are five key results are reported in this section. The first section (4.1 Intraday Market Dynamic) reports price, volatility and volume changes throughout the London trade day showing significant suppression in the price of tradable silver instruments at the time of the silver fixing, as well as jumps in trade volume and price volatility. The second section (4.2 Fix Period and Returns) surveys the fix periods and returns, finding key structural breaks in fix returns post January 2007, and a structural break in fixing period after May 2012. The third section (4.3 Volume and Volatility Impacts) finds volume and volatility spikes aligned to the start of the fixing, and not the subsequent publication of the fixing result. Combined these three results provide strong empirical support that the fixing does indeed still have an impact on public silver markets thus addressing the first research question.

The final two sections (4.4 Returns and 4.5 Predictability) provide strong empirical support that the silver fixing does create an economic trade advantage for fixing participants. The returns analysis shows the size and timing of adjusted returns, while the prediction analysis reports the power of pre-fixing trades to correctly predict the fixing price direction. In both cases, trade advantages are shown to peak in the first two to four minutes following the start of the fixing, *before* the fixing has concluded and the results are made public.

All sections show a dramatic impact following the introduction of contemporaneous silver futures trading, in late 2006. Results for all analysis, be it volume, volatilities, returns or predictability, show more material and more significant outcomes post January 2007.

4.1   INTRADAY MARKET DYNAMICS

By market dynamics I refer to the price, volatility and volume changes thought the trade day. The first of these, price, is shown in Figure 2. This figure illustrates the intraday price dynamics of silver futures throughout the London trade day. It plots the average cumulative unadjusted returns (**CUR**) referenced to the start of the silver fixing, from 8am through to 7pm (London). Effectively, this graph shows the average relative price of the silver contract throughout the day, referenced to the average price of the contract just prior the start of the silver fixing.

The chart's most prominent feature is the sharp 10 bps drop in price around the time of the silver fixing. The price of the publicly traded silver instruments appear suppressed for approximately 10 minutes before and after the start of the silver fixing.

<< Figure 1 roughly here >>

Other features of the trade day are also visible. The gold fixings appear to have a similar, albeit attenuated, negative effect on silver prices. A 2-3 bps dip is observed at the time of the AM gold fixing, and a 4-5 bps dip is observed around the PM gold fixing. The opening of the COMEX trading pit, marking the entry of more market participants, induces a +5 bps spike in the silver price, while the pit close partially reverses this gain with a -2.5bps drop. The close of the London trade day (at 17:00) seems to induce a +2 bps rise. The open of the US equity markets seems to induce a +1.5 bps rise while the Platinum and Palladium fixings show no discernible impacts.

Note that while there is significant intraday activity, the net result leaves the silver price largely unchanged. At 9am the price is 8 bps higher than at the start of the fixing, while at 5pm the price is 7 bps higher, a net change of only -1 bps. With the average daily return for

the period being +2.3 bps and that the London trade day contributing -1 bps on average, the balance of the daily change (+3.3bps) is attributable to the US and Asian trade sessions. Finally, the figure clearly shows that the lowest average intraday price levels are those reported around the silver fixing. Sellers using the silver fixing as the benchmark price appear to be filled at the worse intraday price on average over the sample period.

The statistical significance of these price spikes is shown in Figure 3. In this figure the five-minute interval mean returns, and the corresponding confidence intervals, are shown. The "+" marker denotes the average return, the black bar the 95% confidence interval, the dark grey and light grey bars show the 99% and 99.9% confidence intervals respectively.

<< Figure 3 roughly here >>

The statistical significance of the price drop at the time of the silver fixing is confirmed by the negative returns which are significant well beyond 1%. Returns at the time of the COMEX pit open/close also show significance beyond 1%. Impacts from the gold fixings show mixed evidence; returns at the time of the AM fixing returns are significant, whereas returns for the PM fixing do not show significance. Returns at close of the London trading day are significant, whereas returns at the time of the US equity market open are not. No other times show significant returns.

Figures 4 and 5 illustrate the average intraday SI trade volume and the price volatility of XAG.[16] These figures show elevated levels of volume (Figure 4) and volatility (Figure 5) corresponding to the same key intraday events: the silver fixing, the gold fixings, and market open/close events.

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[16] Largely similar results were found for SI price volatility.

<< Figure 4 & 5 roughly here >>

These two figures also place the silver fixing effects into a broader market context. Volumes show an increase of over 300%, and volatility increase by around 40% at the time of the silver fixing. While this represents a local peak in market activity, it is not the global intraday peak: the COMEX pit close shows a 500% increase in volume, and the pit open shows a60% increase in volatility.

In summary, the intraday trade volumes and price dynamics provide strong support for the hypothesis that the silver fixing has an impact on public silver markets[17]. The significant negative price impact (-10bps) and the sharp increase in trade volume (+300%) and price volatility (+40%) all occur around the start of the silver fixing.

The size of the price impact, without context, is all too easily dismissed as potentially immaterial despite its statistical significance. Consider the near quadrupling of the price of silver from $5.14 to $19.50 per ounce over the study period. This increase equates to an average growth of around 10.0% per annum, or *less than 4 bps per day.* Further, over the same period the average daily return on the S&P500 US equities index was a mere +0.7 bps. Within this context, the 10 bps average daily price drop in the 10-20 minutes around the silver fixing, is difficult to dismiss it as economically immaterial. A trader able to capture 10 bps average daily returns would earn approximately 28%[18] per annum.

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[17] While Figures 1 & 2 shows the results for the silver futures, similar results were found for spot silver.

[18] Effective annual rate based on 250 trade days per year and an average daily 10 bps log return.

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4.2 FIX PERIODS & FIX RETURNS

In characterizing the time for the silver fix to complete (the fix period) and (the fix return), the key findings can be summarized as follows:

Characterizing the time required for the silver fixings to complete (the fix period, T_{Fix}), shows T_{Fix} to be largely stable from 2000 through to 2011. Annual average T_{Fix} during these twelve years range from four to five minutes, with interim updates being rare and having little material impact. Approximately 80% of fixings have periods lasting two and eight minutes. From May 2012, this radically changes with the average fix period dropping to two minutes and interim updates becoming common place.

Fix returns (R_{Fix}), the return on spot silver over the fix period, are found to be predominately negative. Over the fourteen year sample period, the fix return is -8.3bps compared to the average daily return in silver of +3.8bps. The result is material and statistically significant, and robust over time. Indeed in spate analysis it is found that negative average fix returns are observed in each of the fourteen years. Fixings show negative returns more than twice as often as positive returns. Further, negative fix returns have on average larger magnitude than positive fix returns. The introduction of contemporaneous silver futures trading has driven a dramatic convergence in returns from spot, futures and the fixing. However, the spread between the fix return and open market returns, while narrower, has remained intact.

4.2.1 Distribution of Fix Periods

The time between the start of the fixing (Noon London) to the broadcast of the fixing results to financial markets, is referred to as the fixing period. The length of the fixing period (in minutes) is denoted as T_{Fix}. Table 2, Panel A reports the distribution of the fixings periods

for the full sample, see rows **n** (number of fixings)**, n%** (percentage of sample), **cumm%** (cumulative percentage of sample). Two-thirds (66%) of fixings require two to six minutes to complete, with only 13% taking less than two minutes, and 21% requiring six minutes or longer to complete. 90% of the fixings are completed within one to eight minutes. The mean period of the fixings across the full sample ($\overline{T}_{Fix}$) is 4.6 minutes.

The fixing end times reflect the broadest dissemination of the fixing results. The result is widely broadcast via financial reporting organizations, and more recently via the websites of Silver Fixing Pty. Ltd. and the LBMA. The fixing announcement is, however, not necessarily the first signal the market receives from the fixing process. On occasion, "updates" are released on Thompson-Reuters market data terminals which inform subscribers as to the current (interim) price before the fixing. On average these updates occur during 12% of the fixings, and within 1.4 minutes of the fixing start. See rows labeled **%Upd** (percentage updated) and $\overline{T}_{Upd}$ (time to update, in minutes) in Table 1, Panel A.

Intuitively, we would expect longer fixings to have a higher incidence of updates, and this is largely borne out in the summary statistics. For fixings taking five to 15 minutes, updates occur around 5% of the time. This increases to 17% for fixings 15-20 minutes, to 47% for 20-30 minute fixings, to 79% for 30-45 minute fixings and 80% for 45-60 minute fixings. However, for the short fixings, completed in under five minutes, this trend is reversed with the incidence of updates increasing as the fixings get shorter. This is counter intuitive, and hints at a secondary effect, which is discussed below in detail.

To see the net impact of these updates, T_{1st} is used to denote the period from the start of the fixing to the first update. For the majority of fixings (88%) there are no updates, so the final fixing result is the first (and only) signal from the fixing, ie. $T_{1st} = T_{Fix}$. However, for the fixings with updates, T_{1st} will by definition be smaller than T_{Fix}. That is, the updates act to reduce the effective time market participants have to wait for information, at least for those with the necessary real-time terminals. Due to the relatively low frequency of occurrences, the net effect on $\overline{T}_{1st}$ is rather muted. For the overall sample, $\overline{T}_{1st}$ is 4.2 minutes compared to

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4.6 minutes of $\overline{T}_{\text{Fix}}$. Updates have reduced the average time to first signal by around 24 seconds. This marginal impact can be seen by comparing rows $\overline{T}_{\text{1st}}$ and $\overline{T}_{\text{Fix}}$ in Table 1, Panel A.

More insight can be gained by observing the evolution of these variables across each years in the sample, as detailed in Table 1, Panel B. Fixing periods ($\mathbf{T}_{\text{Fix}}$) remain largely constant from 2000 through to 2011. During these first twelve years, $\overline{T}_{\text{Fix}}$ ranges from 4.2 to 6.3 minutes. After 2011, the average fixing period drops to 2.6 minutes in 2012, and then to 2.1 minutes in 2013.

4.2.1.1 Post May 2012

After May 2012 there appears to have been structural change and this hints at a policy, procedural or technology change in the conduct of the fixing. This abrupt change is unique to the silver fixing. While not presented separately here, analysis of the other precious metal fixings (Gold, Platinum and Palladium) do not show a similar change around this time. This lack of commonality with the other fixings suggests that the change does not originate from Thompson Reuters, the financial data provider. Direct enquires as to nature of these changes, addressed to the London Silver Fixing chair, have yet to be answered and the London Silver Market Ltd. public website[19] is silent on the matter.

The proportion of fixings with updates (**%Upd**) and the time to the first update ($\mathbf{T}_{\text{Upd}}$) exhibits a radical shift after May 2012. From 2000 through 2010, $\overline{\%Upd}$ ranges from 1% to 6%. However, in 2011 this jumps to 15%, in 2012 it is 48%, and by 2013 some 73% of fixings feature at least one update. From 2000 through 2010, $\overline{T}_{\text{Upd}}$ ranges from 3.6 to 7.0 minutes. In 2011 this drops to 2.2 minutes, in 2012 it is 24 seconds, and by 2013 it is only 18 seconds. Shorter fixings, more frequent updates, and reduced average time to the first update has a powerful combined effect on the average time to the first market signal ($\overline{T}_{\text{1st}}$). While

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[19] www.silverfixing.com

relatively steady at 4-5 minutes from 2000 to 2011, $\overline{T}_{1st}$ drops shortly thereafter: in 2012 it is

1.6 minutes, by 2013 it is a mere 24 seconds.

Breaking the sample into pre and post May 2012 cohorts crystalizes this structural

change in the silver fixing (see columns <'12 and ≥ '12 of Table 2, Panel B). Fixing periods

roughly halve ($\overline{T}_{Fix}$ drops from 5.0 to 2.3 minutes), updates go from being a rarity to common

place ($\overline{\%Upd}$ jumps from 4% to 60%), and updates occur much faster ($\overline{T}_{Upd}$ drops from 4.2

minutes to 24 seconds). The net effect of these changes is a collapse in the time to the first

fixing signal hitting the market, with $\overline{T}_{1st}$ dropping from 4.8 minutes to 1.0 minute. This is

illustrated in Figure 6 below which presents the empirical cumulative distributions functions

of $\overline{T}_{1st}$ and $\overline{T}_{Fix}$, both before and after May 2012.

<< Insert Figure 6 – Distribution of Fix Periods >>

4.2.2   Distribution of Fix Returns

Unadjusted returns are calculated for each fixing by taking the spot mid-point price

immediately before the fixing as the initial price and the published fixing price as the terminal

price. The natural logarithm of the ratio of these two prices is scaled to basis points (bps) with

the resulting log return denoted as $\mathbf{R_{Fix}}$ and referred hereafter as the "**fix return**".

Referring again to Table 2, Panel A row $\overline{R}_{Fix}$, note that the average fix return for the

full sample is -8.3 bps, significant to 0.1%. This is somewhat startling. As previously

outlined, the average daily return on silver was +3.8 bps for the same period. This makes the

−8.3 bps $\overline{R}_{Fix}$ result curious on two counts. Firstly, the inverted polarity, and secondly, it is

twice the absolute magnitude of the average *daily* return. Recall that the average fixing lasts

less than five minutes whereas the daily returns cover a 24 hour period.

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Looking across the fix period groupings, columns **<1** through **[45-60)**, *all* groupings demonstrate negative returns across the fixing. Most groupings show significance at 0.1% with magnitudes ranging between one to four times of average daily returns. We see that $\overline{R}_{Fix}$ is somewhat proportional to the fixing period $\overline{T}_{Fix}$. For fixings less than one minute, $\overline{R}_{Fix}$ is −3.3bps, which declines to -15.7bps for fixings between eight and nine minutes. However, this relationship is not strictly monotonic.

Separating out fixings with positive, negative and flat (zero) returns, the ratio of negative to positive fixings is denoted by **Neg:Pos**. A number above 1.0 indicates more negative fixings. A proportion z-test for equality is used to test significance of the imbalance between the number of positive and negative days, *, ** and *** denoting 5%, 1% and 0.1% significance. The proportion of fixings during which there was no price movement, is denoted by **%Flat.**

The "**Neg:Pos**" row Table 2, Panel A, shows that on average there were 2.3 times as many negative, or down, fixings as there were positive, or up, fixings over the period. The likelihood of this being a random result is less than 0.1%. This result holds for all period groupings, not one shows a higher proportion of positive fixings. Over the same period, daily price moves were positive 1725 times, negative 1618 times and flat 52 times. That is, slightly more positive days but not significantly more.

This asymmetry between negative and positive fix returns is not limited to just the proportion of positive and negative days. Having segregated positive and negative return fixings, $\overline{R}_p$ and $\overline{R}_n$ denote the average fix returns of each of these cohorts and the calculated difference in the magnitude of these returns is $\overline{R}_p$ - | $\overline{R}_n$ |. A two sample t-test, assuming unequal variances, is used to test the significance of this difference. The corresponding rows in Table 2, Panel A, show that over the sample period $\overline{R}_n$ is -19.6bps while $\overline{R}_p$ is +14.8 bps. This difference in magnitude of return (4.8bps) is significant to 0.1%. Again, this result holds for all period groupings, not one showing a higher return magnitude for positive fixings.

The consistency of these returns results over the fourteen year sample is shown in Table 1, Panel B where the statistics are presented by year. While there is considerable variation year-to-year, the following key findings hold for *all* years;

a) $\overline{R}_{Fix}$ is negative for each year and is significant at 0.1% for most years, the exceptions being 2011 (1% significant) and 2010 (no significance). $\overline{R}_{Fix}$ ranges from -0.5bps (2010) to -16.6bps (2008). Post May 2012, $\overline{R}_{Fix}$ is slightly above the sample average, the pre May 2012 average is -8.8bps compared to the post May 2012 average of -5.3bps. However, the materiality of this is debatable. Note that 2005, 2007 and 2010 show higher $\overline{R}_{Fix}$ than 2012 and 2013. As such, the change post May 2012 (evident in $\overline{T}_{1st}$ and $\overline{T}_{Fix}$) is not observed in $\overline{R}_{Fix}$. Pre and post January 2007 shows a similar increase (decrease in the negativity) in $\overline{R}_{Fix}$ of approximately 2.4bps. As such, the introduction of electronic trading in the futures market appears only to have a muted impact, if any, on this result.

b) **Pos:Neg** shows there are more negative fixings than positive fixings in all years. This is significant to 0.1% for most years, the only exceptions being 2011 (1% significant) and 2010 (no significance). **Pos:Neg** ranges from 1.1 times (2010) to 14.5 times (2000), with the highest imbalances witnessed in the earlier years (2000-2002). Similarly, there is no dramatic shift pre/post 2012, with the ratio adjusting from 2.4 times (pre 2012) to 2.0 times (post 2012). The change pre/post January 2007 is more significant, 3.1 times (pre 2007) versus 1.9 times (post January 2007), again this is largely driven by the front years.

c) $\overline{R}_p$ - | $\overline{R}_n$ | shows that negative fix returns are larger than positive fix returns in all years on average. The annual results are less significant with six of the 14 years showing significance at 5% or better. No significant change is noticeable pre/post January 2007 and pre/post May 2012.

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Combined, these results suggest the pricing dynamics of the fixing diverge from the pricing dynamics of the open silver markets. To investigate this further R_{Fix}, is compared to the returns in spot silver and the silver futures, denoted R_{Spt} and R_{Fut} respectively, over the same fixing period. Daily returns on silver are calculated from contiguous fixing results, and are denoted by R_{Day}.

In Figure 7, two charts plot the empirical cumulative distribution function (CDF) of each of these four returns, R_{Fix}, R_{Spt}, R_{Fut} and R_{Day}. The top chart shows a wide range of returns, +/- 200 bps, this compares the daily silver returns, R_{Day}, and the three intraday returns, R_{Fix}, R_{Spt} and R_{Fut}. The bottom chart narrows the range of returns, to +/- 20 bps, "zooming in" on the intraday distributions, to highlight differences between the three distributions. Specifically, comparing R_{Fix} to the public market instrument returns R_{Spt} and R_{Fut}.

<< Insert Figure 7 – Distributions of Fixing Return (2000-2013) about here >>

Referring to the top chart first, the differences in dispersion of the daily returns, R_{Day}, relative to the intraday distributions, R_{Fix}, R_{Spt} and R_{Fut} is very apparent. Within +/- 50bps covers about 26% of the R_{Day} sample and close to 95% of the intraday returns samples. This result is expected given that variance scales with time, R_{Day} covers 24 hours while the other three returns cover, on average, less than five minutes.

Note the daily return distribution intercepts the 50% horizontal (ie. the median) slightly to the right of the 0 bps vertical, whereas the R_{Fix}, median is found slightly to the left. As such, the polarity of the medians match those of the averages, $\overline{R}_{Fix}$ and $\overline{R}_{Day}$. This provides further confirmation that averages reflect an underlying shift in the distribution, rather than a small number of extreme values.

Despite the relatively large scale of the top chart, the differences between $\mathbf{R_{Fix}}$ and $\mathbf{R_{Spt}}$ and $\mathbf{R_{Fut}}$ in the negative region of the distributions (left of the 0 bps vertical) are visible. The positive region of the distributions, however, looks largely similar. Also noticeable is the discontinuity at 0 bps for all three distributions. This is a common artifact of discrete, rather than continuous, prices.

The bottom chart focuses on the +/- 20 bps return range for the $\mathbf{R_{Fix}}$, $\mathbf{R_{Spt}}$ and $\mathbf{R_{Fut}}$ cumulative distribution function (CDFs), allowing closer inspection and comparison of the intraday return distributions. Looking left to right, note the following features;

a) *From -20bps to -5bps:* There is a wide difference between the CDF of $\mathbf{R_{Fix}}$ and those of $\mathbf{R_{Spt}}$ and $\mathbf{R_{Fut}}$ with spreads of ranging 15 to 30%. This is in contrast to the CDFs of $\mathbf{R_{Spt}}$ and $\mathbf{R_{Fut}}$ which appear to track each other relative tightly, with typical spreads less than 1%.

b) *From -5 bps to 0 bps:* The CDFs of $\mathbf{R_{Spt}}$ and $\mathbf{R_{Fut}}$ start to diverge as they approach 0 bps. The initial spread of 1% widens to 10%. Just before 0 bps, the spreads between the CDF of $\mathbf{R_{Fix}}$ and those of $\mathbf{R_{Spt}}$ and $\mathbf{R_{Fut}}$ are 30% and 20% respectively.

c) *At 0bps:* There is a discontinuity in each of the CDFs driven by a large incidence of zero returns (prices remaining flat over the fixing). The largest is in spot returns, with 42% of $\mathbf{R_{Spt}}$ indicating zero returns. This compares with 23% and 11% for $\mathbf{R_{Fut}}$ and $\mathbf{R_{Fix}}$ respectively. It appears that price movements in the spot, and to a lesser degree the futures, are fairly subdued during the fixing period. This result is consistent with the **%Flat** statistic from Table 1.

d) *From 0 bps to +5 bps:* the CDFs for each of the three returns converge to each other, from an initial spread at 0bps of 10% to only 1% at +5 bps.

e) *From +5bps to 20bps:* The CDFs for each of the three returns converge, with observed spreads typically less than 1% for the remainder of the distribution.

4.2.3   Pre & Post 2007 – The introduction of electronic futures trading

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Competitive pressure on the COMEX/NYMEX[20] from its rival, the Chicago Board of Trade (CBOT), forced NYMEX to adopt CME's Globex electronic trading platform in late 2006 despite having previously resisted the move to screen trading. Initially offered to complement its tradition floor trading operations, the trade quickly migrated from the trading floor to computer screens.

Of particular relevance to this study is the impact on trading hours triggered by this platform change. The COMEX pit trading hours are from 8:25am to 1:25pm (New York), which usually covers to 12:25pm to 6:25pm (London). As such the trade session did not cover the silver fixing. Globex, on the other hand, operates nearly 24hr per day[21] and does overlap the silver fixing. To see the impact of this change in market structure, refer to Figure 8 below which illustrates the distributions of returns pre and post January 2007.

<< Insert Figure 8 – Distributions of Fixing Return pre and post January 2007 about here >>

Comparing the two periods shows:

a) Post January 2007, any difference between spot and futures returns have all but disappeared, their return distributions look equivalent. The divergence from -5bps to +5bps has closed from 73% pre 2007, to 6% post January 2007. Also the collapse of the spread between $\bar{R}_{Fut}$ and $\bar{R}_{Spt}$, from 4% to near 0%, is shown by the near overlapping annotating verticals.

b) The discontinuity at 0 bps has dramatically reduced. Pre 2007, the occurrence of these zero returns were c. 73%, 41% and 16% for of R_{Spt}, R_{Fut}, and R_{Fix}

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[20] http://online.wsj.com/news/articles/SB115187952655396585
[21] Sunday – Friday 6:00 p.m. – 5:15 p.m. (New York) as outlined in
http://www.cmegroup.com/trading/metals/precious/silver_contract_specifications.html

respectively. Post 2007, these had collapsed to 5-6% for all three returns. The overall

size of these discontinuities reduced and the difference in size eliminated.

c)   The spread between R_{Fix} and the other two returns has also narrowed materially. Post

2007 it is typically c.10%, whereas pre 2007 it ranged from $20 - 40\%$.

The statistical significance of these findings can be assessed with a two-sample

Kolmogorov–Smirnov (K-S) test for equally of two sample distributions. The results are

presented in Table 3, with Panel A showing the comparison between the fixing and spot

returns, Panel B comparing fixing and future returns, and Panel C comparing futures and spot

returns. In each Panel, results are provided for the full sample period (2000-2013), pre and

post the introduction of contemporaneous electronic futures trading in late 2006 (2000-2006

and 2007-2013).The post January 2007 sample is further decomposed into pre and post the

May 2012, to assess the structural change witnessed in the fixing periods.

<< Insert Table 3 - KS Tests about here >>

Table 3, Panels A and B show we can reject the null hypothesis that the fixing returns

and spot (futures) returns share a common distribution, for the full sample and each of the

sub-samples. The significance is better than 0.1% in all cases, with p-values typically smaller

than 10^{-10}. The fix returns (R_{Fix}) are significantly different to open market returns (R_{Spt} and

R_{Fut}). Also apparent is the significant convergence between the fixing and the open market

returns post 2007. Pre 2007 the K-S statistic is 0.41 compared to 0.12 post January 2007,

noting the similar sample sizes. This confirms Figure 7, namely that the gap between the

distributions has narrowed since January 2007, but nonetheless remains significant.

Table 3, Panel C reports the comparison of the two open market returns, and here we

do see changes to significance. Prior 2007, we can reject the equality of R_{Spt} and R_{Fut} with

near certainty, p-value < 0.1%. Post January 2007, the p-Value is 2.8%. We can no longer

reject equality at 1%. Further decomposing the post 2007 sample into pre and post May-2012 sub samples, shows p-Values of 13.2% and 29.6% respectively[22]. That is to say, we cannot reject the possibility that the distributions are in fact the same.

Running the same KS test over the sample period with a one-year sliding window yields Figure 9 below. The top chart compares spot versus futures returns ($\mathbf{R_{Spt}}$ and $\mathbf{R_{Fut}}$) while the bottom chart compares spot and fixing returns ($\mathbf{R_{Spt}}$ and $\mathbf{R_{Fix}}$).[23] The p-value of the KS test is plotted against time to highlight the evolution of the difference in the return distributions. Points below the horizontal line at 1% (10^{-2}) indicate rejection of the null hypothesis that the two samples are drawn from the same underlying distribution at 1% significance. Returns appear to have largely converged after January 2007 and this stands in contrast to the period prior 2007.

<< Insert Figure 9 – Comparisons of return distributions >>

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[22] Note, the large disparity in samples sizes of the two periods makes direct comparison of the K-S statistic meaningless.

[23] The same analysis was conducted comparing futures and fix returns, yielding largely similar results.

4.3   VOLUME AND VOLATILITY IMPACTS

Two key findings emerge from the analysis of trade volume and price volatility data. Firstly, both volumes and volatilities peak immediately after the start of the fixing, in the opening two to four minutes of the fixing. These increases are both material (>300% increase in trade volume, +30% increase in volatility) and statistically significant. Secondly, since the introduction of contemporaneous futures trading, in late 2006, overall levels of both volumes and volatilities dramatically increase, by as much as ten to twenty fold.

4.3.1   Trade Volume

Results for the trade volumes are presented in Table 4, and with nominal trade volumes illustrated in Figure 10 relative trade volumes illustrated in Figure 11. Table 4 splits out the sample into pre 2007 (Panel A) and post January 2007 (Panel B). Within each panel, both start of fixing and end of fixing aligned results are presented for the fifteen one minute intervals before and after the start (end) of the fixing ($-14 \leq i \leq +15$).

<< **Table 4 roughly here** >>

Average one minute interval volumes ($\overline{\Delta VM_i}$) increase from 1 to 3 contracts per minutes per 2007, to over 50 contracts per minute post January 2007. The median volumes (P_{50}) illustrate this further. Pre 2007 the majority of intervals show zero contracts changing hands, ie. no trading, whereas after 2007 the median exceeds 30 contracts per minute (see intervals i = 1, 2).

The table presents the t-statistics of the one-sided, paired t-tests for $\overline{VM_i} > \overline{VMref}$, using the untransformed data, in column $\overline{VM}$. The results of the one-sided, t-tests of $\overline{\Delta VM_i} > 0$, using the log transformed, zero-substitute data, is presented in column $\overline{\Delta VM}$. Pre 2007 (Panel A), both tests find a significant increase in volume immediately after the start of the fixing,

and no significant increase following the end of the fixing. Post January 2007 (Panel B), shows peak volumes 2 minutes after the start of the fixing ($i = 2$, $\overline{VM_i} = 53.4$ contracts/min), and two minutes before the end of the fixing ($i = -1$, $\overline{VM_i} = 52.9$ contracts/min), with significant increases in volume consistently detected 12 minutes before the start of the fixing, lasting five minutes past the end of the fixing. The two t-tests lead to largely the same conclusions on significance, with the relative volume test ($\overline{\Delta VM}$) reporting generally higher t-statistics.

The summary statistics in Table 4 are illustrated in Figure 10, which focuses on the post January 2007 trade volumes. The top chart illustrates the slow run up of average trade volumes ($\overline{VM_i}$) in the ten minutes before the fixing, the near *quadrupling* of $\overline{VM_i}$ in the first two minutes following the start of the fixing, and the subsequent run down of volumes.

<< Figure 10 roughly here >>

The group of four histograms, illustrate; a) the distribution of the reference level (*VMref*), b) the volume immediately following the start of the fixing ($VM_{1,d}$), c) the difference between the volume before the fixing start and reference level ($VM_{0,d}$ - *VMref*) and d) the difference immediately after the start of the fixing ($VM_{1,d}$ - *VMref*).

These difference distributions confirm the change in average volume is driven by a shift in the distribution of VM_i and not by extreme values. The heavy skew in these distributions should caution the interpretation of marginal t-tests. However, the t-statistics are so large (generally >6 and in some cases >20) that the significance of the change in volumes levels is not in question.

To underscore this finding, the relative volume change results are illustrated in Figure 11. The top chart shows average change in volume $\overline{\Delta VM_i}$, and the 95% and 99% lower

confidence bounds of the average. Here the analysis window is aligned to the start of the fixing, the center of the window aligned to noon (London). The reference interval ranges from 11:30am through to 11:45am and is marked by the omission of confidence bounds about the mean. 0% indicates no change in trade volume relative to the average volume across the reference interval.

<< Figure 11 roughly here >>

Trade volume peaks in the opening two minutes of the fixing, well before the majority of the fixings are complete. Further, significant increases in trade volume seem to proceed the start of the fixing, starting around 11:50am. However, the largest change in the relative volume occurs immediately following the fixing start.

The group of four histograms illustrate the relative volume distributions (ΔVM_i) at for points in time, a) the end of the reference period (t_i= 11:45am), b) immediately after the start of the fixing (t_i= 12:01am), c) immediately before the start of the fixing (t_i= 12:00am), and d) fifteen minutes after the start of the fixing (t_i= 12:15am). These distributions confirm the increase in $\overline{\Delta VM_i}$ is driven by a shift in the distribution of ΔVM_i , and not by extreme values. Also note the reduction in skew, from the log transform. This

Combined, these results support the first hypothesis that the fixing does impact public markets. Further, this result is inconsistent with the existence of a market reaction on publication of the fixing price. Intuitively, we expect volumes to spike following the introduction of information to the market. If publication of the fixed price were to mark new information to the market, we would expect to observe elevated volumes distributed around the fixing publication times. What the results show is a clustering of trades immediately following the fixing start, rather than following the fixing publication time.

Any Silver Linings?

4.3.2   Price Volatility

Results for the price volatility of spot silver (XAG) are presented in Table 5 and

illustrated in Figure 12. While not presented separately here, the results for SI are largely the

same and the observations made below apply equally. Table 5 splits out the sample into pre

2007 (Panel A) and post January 2007 (Panel B). Within each panel, both start of fixing and

end of fixing aligned results are presented for the fifteen one minute intervals before and after

the start (end) of the fixing ($-14 \le i \le +15$).

<< Table 5 roughly here >>

Inspection of the summary statistics shows the same dramatic change in volatilities

trading hours triggered by the introduction of the electronic trading platform in late 2006.

Average interval one minutes volatility ($\overline{\Delta V_i}$) increase from 0.4 to 0.9 bps per minutes Per

2007, to over 7.0 bps per minute post 2007. The median volatilities (P_{50}) illustrate this further,

pre 2007 all intervals show zero volatility, ie. no price changes, whereas after January 2007

medians typically exceed 5.0 bps/minutes (see intervals $i > -9$).

The table presents the t-statistics of the one-sided, paired t-tests of $\overline{V_i} > \overline{Vref}$, using the

untransformed data, in column $\overline{V}$. The results of the one-sided, t-tests of $\overline{\Delta V_i} > 0$, using the log

transformed, zero-substitute data, is presented in column $\overline{\Delta V}$. Pre 2007 (Panel A), both tests

find significant increase in volatility following the start of the fixing, and decreasing volatility

following the end of the fixing. Post January 2007 (Panel B, Table 5), shows peak volumes 2

minutes after the start of the fixing ($i = 2$, $\overline{V_i} = 7.8$ bps/min), and one minute before the end of

the fixing ($i = -1$, $\overline{V_i} = 8.7$ bps/min), with significant increases in volatility are consistently

detected eight minutes before the start of the fixing, lasting two minutes past the end of the

fixing. The two t-tests lead to largely the same conclusions on significance, with the relative

volatility test ($\overline{\Delta V}$) reporting slightly higher t-statistics.

Referring to Figure 12, the top chart shows average change in volatility $\overline{\Delta V_i}$, and the 95% and 99% lower confidence bounds of the average. Here the analysis window is aligned to the start of the fixing, with the center of the window set to noon (London). The reference interval ranges from 11:30am through to 11:45am and is marked by the omission of confidence bounds about the mean. The bottom chart shows the same data, however, the analysis window is aligned to the end of the fixing. The reference interval ranges from 15 to 30 minutes after the completion of the fixing, and is similarly marked by the omission of confidence bounds about the mean. In both cases, 0% indicates no change in trade volume relative to the average volume across the reference interval.

<< Insert Figure 12 - roughly here >>

As with the trade volume in SI, we see the abrupt spike in price volatility in the opening two minutes of the fixing. These peak at +37 %, and represent an increase in volatility from about 5.7 bps/minute to over 7.7 bps/minute. Around 10 minutes after the fixing start, the volatility seems to return to a steady state, albeit at a level approximately 15% higher than the reference period. Price volatility seems to lag the trade volume response, with significant changes in $\overline{\Delta V_i}$ starting to be visible only four minutes prior to the start of the fix.

Viewed from the perspective of the end of the fixing, as in the bottom chart of Figure 10, it is clear that spike in average price volatility precedes the fixing end. The four one minute intervals before the fixing concludes (i = -4 to -1) all show higher levels of $\overline{\Delta V_i}$. While distributions plots of ΔV_i are not shown here separately, they do confirm the results are driven by a shift in the underlying distribution.

Both SI and XAG exhibit this large, statistically significant spike in price volatility immediately following the fixing start. As argued in the trade volume analysis, increased

volatility is not expected until after the publication of the fixing result (fixing end). This reinforces findings from trade volume analysis that suggests that information leaks from the fixing ahead of the result publication. This result is robust to the choice of volatility estimator. Similar results are obtained using both the Parkinson and the Rogers-Satchell estimators in place of the Garman-Klass estimator.

4.4 RETURNS

The difference in returns (**DR**) measures the value of knowing the direction the fix ahead of the result being published. It is the difference between the unadjusted returns (**UR**), available to the uninformed trader holding a long position, and the adjusted returns (**AR**), available to the price direction informed trader, as set out in Section 3.6.

The results are reported in Tables 6, 7 and Figures 13 through 16. Combined, the returns analysis provides strong empirical evidence for our second research question; fixing participants are indeed granted an economic trade advantage. This information advantage gives informed traders an average up to 25 bps *per fixing*, with most of the advantage in the opening two to four minutes of the fixing.

The introduction of the contemporaneous futures trading in late 2006 had a profound impact on this information advantage, doubling the available trading edge and removing any economic return advantages following the fixing publication. While there are substantive variations year to year, the profitability of the opening minutes of the fixing is robust over the fourteen year sample.

Figure 13 illustrates the value of knowing the fixing direction at times aligned to the start of the fixing. The top chart shows $\overline{DR_i}$, and associated confidence intervals, for one minute intervals from 11am through 1pm, centered on the start of the fixing.

<< Please insert Figure 13 roughly here >>

It demonstrates that there are trade advantages available to the informed trader five minutes either side of the fixing start. These peak at about 5.0 bps per minute (at i=1 and 2), and are significant at 0.1% or better, suggesting the trade advantage in the opening two minutes (>10bps) is economic.

To highlight this further, the bottom chart shows the cumulative DR, referenced to the start of the fixing. Differencing the CDR between any two points in time yields the net gain the informed trader has over the uninformed long position. For example, the informed trader holding a position from 11:50am (-10bps) through to 12:05pm (+15bps) experienced on average a 25 bps return advantage over being long over the same period. A trader who learns of the direction somewhat later, at say 12:02pm (+9 bps), would only have a 6 bps edge over an uninformed position. As can be seen by the gradient of the CDR curve, the information advantage has the maximum value in the opening two minutes of the fixing. All trade advantages appears to have been eroded five minutes after the fixing start.

The returns for sport silver (XAG) are provided in Table 6, with the results for silver futures (SI) being largely similar. The table splits out the sample into pre 2007 (Panel A) and post January 2007 (Panel B). Within each panel, both start of fixing and end of fixing aligned results are presented for the fifteen one minute intervals before and after the start (end) of the fixing ($-14 \leq i \leq +15$). Table 7 follows the same construction and reports the associated cumulative returns (**CUR**, **CAR**, **CDR**). The cumulative returns are zeroed at the interval immediately before the start (end) of the fix, for the start (end) aligned results.

<< Please insert Table 6 roughly here >>

<< Please insert Table 7 roughly here >>

Any Silver Linings?

The unadjusted returns pre 2007 show only marginal and sporadically significant returns, with only one (at $t_i = 12:02$, $\overline{UR_2}$ = -0.5 bps) significant past 5%. After 2007, however, a cluster of negative returns can be found from $11:55 < t_i < 12:05$, all with returns under -0.5bps, peaking at -1.4bps, and all significant past 5%, most past 1%.

The cumulative effects of these one minute returns further highlight the difference between pre and post 2007. Pre 2007, the fifteen minutes prior the fixing start shows a 1.7 bps decline and a further 1.6bps decline after the fixings. This yields a -3.3 bps return from 11:46 through to 12:05. Post January 2007, the fifteen minutes prior the fixing start shows a 4.8bps decline and a further 4.3 bps decline after the fixings. This yields a -9.1 bps return, from 11:46 through to 12:07, nearly three time larger the pre 2007.

Significant adjusted returns are found in the first four minutes immediately following the start of the fixing, both pre and post January 2007. These peak at 4.3 bps per minute post 2007 (i=2), and 1.2 bps (i=4) pre 2007. When aligned to the end of the fixing the post January 2007 results show only small adjusted returns after the fixing end, 1 bps. Pre 2006, there appears to be small, but significant, adjusted returns both before and after the end of the fixing.

Again, the cumulative effects of these one minute returns further highlight the difference between pre and post January 2007. The fifteen minutes prior the fixing start shows no material CAR (0.3 bps) pre 2007, and a relatively small amount +3.4bps, post January 2007, compare the opening minutes of the fix. The first two minutes following the start of the fix report CAR of +1.5 (+7.7) bps with CAR peaking at +8.2 bps at i=+15 (+11.9 bps at i=+7) pre (post) 2007. 80% of the peak CAR is achieved within 9 minutes of the fixing start, pre 2007, and only 4 minutes post 2007.

When viewed from the end of the fix, another key difference between the pre / post January 2007 period emerges. Pre 2007, the CAR is somewhat symmetrical around the end of

the fix, starting at -4.3 bps (i=-14) and ending at +4.0 bps (i=-15), with the highest rate of change occurring in the five minutes before and after the fixing (-5 < i ≤ +5). Post January 2007, virtually all the change in CAR occurs *before* the end of the fixing. The CAR increase from -12.9 bps (i= -14) to a peak of +1.5 (i=+3) , finishing at +0.5 (i=+3). That is, any value in knowing the fixing direction after its publication appears have vanished post January 2007.

The robustness of the trade advantage over time is shown in Figure 14. The top chart shows the average DRs (left axis) across two-minute intervals with reference to the start of the fixing, and grouped by calendar quarter. Overlaid is the silver price (right axis) for the same period.

<< Please insert Figure 14 roughly here >>

The aggregate height of the bars indicate the sum of the average DRs from 11:48am to 12:12pm, i.e. the cumulative of difference in returns (CDR) from 12 minutes before the start of the fixing to 12 minutes after. Within each bar the CDR is decomposed into 2 minute intervals. The chart makes two key points. First, the overall CDR has remained positive for all 28 calendar quarters in the study period. This has varied from +7 bps (2Q07) to +83 bps (3Q08), but has generally remained above +10 bps. Second, the opening two minutes of the fixing (light green bars) consistently yields the largest DRs, and is always positive.

As seen by the silver price overlay, the profitably of the trade advantage does not seem to be driven by the silver price or the change in the price - these results are not capturing any broad bull / bear markets effects.

The bottom chart shows a heat map of the DRs, further identifying profitability of informed trades across calendar quarters and time of day. It illustrates the consistency of the profitability of the opening two minutes, comparatively to the other two-minute intervals

around the time of the fixing. The opening interval shows profitability for all quarters, whereas the interval before (after) is profitable to the informed trader 26 (25) of the 28 quarters. The further the interval is from the fixing start, the more variable and less profitable the interval returns become.

As a final note, consider the contrasting CDR profiles of 2007 and 2011 as depicted in Figure 13. In particular, observe the two key features: a) no significant CDR prior the fixing start in 2007, compared with the +10 bps of CDR that appears to be generate in the 5-10 minutes prior the fix in 2011, and b) the maximum CDR in 2007 is approximately +9 bps, in 2011 CDR reached over +40 bps. Not only has the value of the information increased fourfold, it has gone from barely covering trading costs (10 bps) to being highly profitable. Limits to arbitrage (bid-ask spreads, trading cost) did not change between these two years, yet the opportunity for arbitrage, for fixing participants, increased fourfold. The average +40bps edge over 2011 equates to 172% when annualized.

<< Please insert Figure 15 roughly here >>

4.5 PREDICTABILITY

Market price movements are highly predictive of the fixing price direction, with predictions substantially more accurate after 2007. The price movements in the opening two to four minutes of the fixing show the highest increase in prediction success, in some cases surpassing 90%. Predictability is strongly influenced by the magnitude of fix return: large absolute fix returns are significantly more predictable. That is, not only are the trades quite accurate in predicting the fixing direction, the more money is available to be made, the more accurate the trade becomes. This is suggestive of information leaking from the fixing to these public markets before the broad release of the fixing result. These findings are drawn from Table 8 and Figure 17, which present the results for silver futures for 2000-2006 (Panel A) and 2007-2013 (Panel B). The results for spot silver, not shown, are largely the same.

The graphs in Figure 17 show the predictability of the fixing direction as a function of minutes from the start of the fixing. The top graphs cover fixings between 2000-2006 and the bottom 2007-13. The percentage of correct predictions is given on the vertical axis (P) for a range of cut-off intervals ($-20 \leq i \leq +15$). The vertical axis represents the proportion of fixings for which the fixing price direction ($FIXDIR_d^*$) was correctly predicted by the price direction of the market midpoint up to interval i ($MKTDIR_{i,d}$) for all the days d in the sample (see section 3.6 for further details). Each graph shows three sets of results, corresponding to three sub-samples: a) S_i, the fixings still in progress at the end of cut-off interval i, b) $S_{i,Lrg}$, the fixings with absolute fix returns larger than the median absolute fix return of S_i, and c) $S_{i,Sml}$ and those with absolute fix returns smaller or equal to the median. For the full sample, $P(Si)$ is shown with 95%, 99% and 99.9% confidence intervals based on a proportion z-test. The "large" and "small" fixing sub-sample results $P(S_{i,Lrg})$ and $P(S_{i,Sml})$ are presented by white and black bars respectively.

<< INSERT FIGURE 17 roughly here >>

Any Silver Linings?

4.5.1   Predictability before the start of the fix

Focusing on the pre-fixing start intervals ($-20 \leq i \leq 0$) of the top graph (Pre 2007) in Figure 17, the results show little to no predictability from the pre-fixing market price of silver futures. As the cut-off interval (i) approaches the fixing start, the proportion of correct predictions, $P(S_i)$, does increase, becoming significant from i>-5 onwards. However, $P(S_i)$ remains below 40%, and isn't materially higher than a random draw from one of the three directional outcomes (positive, negative, flat). $P(S_{i,Lrg})$ and $P(S_{i,Sml})$ are largely the same from $-20 \leq i \leq -10$, both are approximately 33%. After i = -10, $P(S_{i,Lrg})$ and $P(S_{i,Sml})$ start to diverge, with $P(S_{i,Lrg})$ increasing and $P(S_{i,Sml})$ decreasing, leading to a 8% difference just before the start of the fixing (at $i=0$, $P(S_{i,Lrg})=43.4\%$ and $P(S_{i,Sml})=34.9\%$).

Post 2007, shown in the bottom graph of Figure 17, the results for $P(S_{i,Lrg})$ and $P(S_{i,Sml})$ are markedly different, while the overall level of predictive success, $P(S_i)$, is only marginally higher. The pre-fixing start intervals ($-20 \leq i \leq 0$) show $P(S_{i,Lrg})$ ranging from 48% to 56%, while $P(S_{i,Sml})$ ranges from 24% to 27%. The large fix return directions are approximately twice as predictable. This is a material change.

4.5.2   Predictability after the start of the fix

Table 8 provides additional detail of the rapid rise in predictability seen after the start of the fixing ($i > 0$) in Figure 17. At each cut-off interval i, results for each of the three sub-samples (S_i, $S_{i,Lrg}$, $S_{i,Sml}$) include the sample size (n), median absolute fix return (R_{50}), proportion of correct predictions (P) and the chi-square test statistic (χ^2). The significance of the proportion z-test of $P = {}^1\!/_3$ and the chi-squared test of $P(S_{i,Sml}) = P(S_{i,Lrg})$, are appended to the P and χ^2 results with *, **, and *** denoting 5%, 1% and 0.1% respectively. The results for P and χ^2 are presented at three different levels of materiality, Δmin = 0, 5 and 10 bps.

Fixings with absolute fix returns below Δmin are deemed to be "flat", rather than positive or negative. The pre and post 2007 results are presented in Panel A and B respectively.

<< INSERT TABLE 8 roughly here >>

Pre 2007, there is a distinct increase in the overall level of predictability, $P(S_i)$, from 39.2% ($i = 0$, the interval before the start) to 64.6% ($i = +7$, seven minutes after the start). These figure are for the mid-case $\Delta min = 5$ case, with $\Delta min = 0, 10$ bps showing largely the same results. It takes four minutes ($i = 4$) for $P(S_i)$ to exceed 50%, and generally $P(S_{i,Sml})$ is significantly smaller than $P(S_{i,Lrg})$. The opening two minutes ($i = 1, 2$) are the exceptions, showing both a dip in $P(S_i)$ and inversion of the $P(S_{i,Sml})$, $P(S_{i,Lrg})$ relation with $P(S_{i,Lrg})$ performing very poorly. This is largely attributed to the lack of volatility in these intervals (see section 4.x) causing the disproportionately large predictions of "flat", rather than positive or negative price directions.

Post 2007, while the same uptrend is visible, there are some marked differences. Considering the mid case, $\Delta min = 5$, the results show $P(S_i)$ increasing to 77.8% ($i = +7$, seven minutes after the start), from a pre start level of 41.4%. The rise is not only higher, but also faster with the $P(S_i)$ to exceeding 50% after the first minute ($i = 1$). A further difference is the significantly larger gap between $P(S_{i,Lrg})$ and $P(S_{i,Lrg})$, which in the opening three minutes almost reaches 50% with $P(S_{i,Lrg})$ exceeding 95% by the fourth minute. This difference in relative $P(S_{i,Lrg})$ and $P(S_{i,Lrg})$ is further confirmed by the materially larger χ^2 statistics.

4.5.3   Robustness to the materiality cut-off

While the key findings are robust to the choice of materiality cut-off (Δmin), the parameter does impact on the result, and noticeably differently pre and post 2007. Pre 2007, the impact on $P(S_i)$ from variations in Δmin is relative minor. For $i > 2$, there is only 2-3% difference in $P(S_i)$ across the three cases of Δmin (0, 5 and 10 bps). Post January 2007, the

difference in $P(S_i)$ is materially larger with higher Δmin resulting in lower $P(S_i)$. At i=2, setting Δmin = 0 results in $P(S_i)$ = 73.1%, whereas Δmin = 10 bps results in $P(S_i)$ = 54.4%.

By increasing Δmin the likelihood of classifying a fixing direction as "flat" ($FIXDIR_d^* = 0$) increases. Pre 2007, the incidence of "flat" fixings was relatively high, leading to fewer incorrect predictions of "flat". Post January 2007, however, the incidence of "flat" fixings are significantly lower, resulting in the drop of predictability drop as Δmin is increased. Finally, note the change in the overall prediction, $P(S_i)$, in driven solely by the change in predictability of small fixings, $P(S_{i,Sml})$. The large fixing sample (S_{Lrg}), by definition, excludes "flat" fixings as S_{Lrg} is conditioned to only include large absolute fix returns. This can be verified by inspecting the P values for S_{Lrg} and S_{Sml} presented in Table 8. At any given interval cut-off interval i, notice $P(S_{i,Lrg})$ remains constant values across the three cases of Δmin (0, 5 and 10 bps) whereas as $P(S_{i,Sml})$ decreases for increasing values of Δmin.

5 CONCLUSION

This study finds strong support for its central hypotheses: a) the London silver fixing *has* an impact on public silver markets, and b) fixing participants are granted an economic trade advantage over the broader market participants. Fixing participants have an exploitable average trade advantage of *25 bps per fixing,* equivalent to *87% per annum return,* over uninformed traders from the knowledge of price direction grained during the fix proceedings. Further, price movements in open market instruments are highly predictive of the price direction. The timing of market reaction to the fixing, as witnessed by increases in trade volume (+300%) and price volatility (+40%), align to the *start* of the fixing. Most of the market reaction takes place in the opening two minutes of the fixing, and well before its conclusion. The subsequent publication of the fixing result shows little to no impact on these measures of market activity. This suggests that front running the fixing result is not only potentially profitable, it is indeed taking place. Further, the advent of contemporaneous futures trading at the time of the fixing increased markedly the scale and significance of all these findings. These findings mirror those found in relation to the London PM gold fixing (Caminschi and Heaney 2013), with silver fixings exhibiting significantly larger abnormalities[24].

Combined, these results can be interpreted in one of two ways. The first is termed the "leakage" interpretation. Under this interpretation, short-term prices of public traded instruments are driven by the London silver fixing. Fixing participants are leaking the price fixing information by trading in the exchange traded instrument prices ahead of the publication of the fixing price. The alternate interpretation is a "market push". Under the

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[24] A rigorous comparison of the two fixings is outside the scope of this study, and is left as a possible extension of this work.

market push interpretation the direction of causality is reversed. Here it is the fixing results that are being driven by the price changes observed in the public markets. Participants of the public markets are "pushing" (manipulating) the short-term prices of the public instruments to influence the fixing results. In essence, the question is whether public markets are watching to see what happens in the fixing, or whether the fixing members are watching the public markets to price to fixing. Neither interpretation should be pleasing to market regulators or broader market participant.

The leakage interpretation is the more plausible. Firstly, the timing of the abnormal volume and price movements in public markets is far more congruent with the leakage interpretation. The jumps in volume and volatility occur shortly after the start of the fixing, when one would expect the initial fixing buyer-seller balance to be established. Yet, under the market push interpretation we would expect participants to start pushing market prices before the start of the fixing. The fixing period is unknown in advance which means any delay would risk missing the opportunity to influence the fixing altogether.

Secondly, consider the asymmetry of information, cost and risk. The fixing participants have visibility to the public markets and the information revealed during the fixing, in particular the aggregate supply and demand balance of their clients. Fixing participants, and certainly fixing members, have an institutional information advantage. To influence the fixing, public market participants would be required to risk capital to initiate a change in the market price. This risk would be in exchange a mere hope of the fixing members reacting to the market price. The members are under no obligation to comply. Further, any repetitive gaming of the public market price would undoubtedly be detected and ignored by the members. This makes the profitability of any trade under the market push interpretation far from certain. The trades under the leakage interpretation do not rely on hope, just simple informational advantage.

The study also finds a 10-12 bps downward bias in the intraday price of silver around the time of the fixing. This represents three times the average daily return on silver over the same

period. Returns across the fixing are negative twice as often as positive returns, and negative returns are significantly larger than positive returns. This yields a further average discount of 6 bps to public market prices. Simply put, the silver fixing is, on average, the worst time of the day to sell, the best time to buy.

The fixing market structure appears, temporarily at least, to induce two 'wedges' between this private price discovery club and the broader public markets for silver. The first is a price wedge between the fixing equilibrium price (restricted to the fixing members) and the open market equilibrium price for silver. This price wedge is not symmetric, introducing a downward bias on the equilibrium fixing price. One argument for an innocent explanation of this effect was recently put forward in the financial press:

> *"The tendency for prices to drop in the afternoon fixing more likely reflects the balance of traders, Norman said. Sellers such as mining companies can often outweigh buyers, said the 54-year-old. "Those that would want to sell would typically use the fix and of course buyers will know that," Norman said. "Producers will typically sell through the fix because they have relationships with bankers on their hedging programs that require an objective price."[25]*

Simply put, it argues the pricing bias is the result of a systemic imbalance in fixing participants rather than any collusive (or manipulative) market behavior. This argument is inconsistent with arbitrage pricing and the empirical evidence. The argument, put forward in defense of the London PM gold fixing, is correct in its assertion that buyers compete with sellers to achieve a lower price. Advance knowledge of the sellers' intent to sell has value and is considered by the buyers. However, *buyers also compete with other buyers*. This competitive tension drives prices to equilibrium, at least in open, competitive markets.

The results show open markets returns (prices) are indeed different to those of the fixing return (prices), statistically significant well beyond 1%. What the results show is that

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[25] http://www.bloomberg.com/news/2014-03-05/london-gold-broker-says-swings-in-prices-no-sign-of-manipulation.html

the fixing reduces potential buyers' ability to compete at the equilibrium price. Tacit, or even explicit, collusion between fixing members could be one explanation for the observed difference in pricing behavior. The collusion theory is further supported by the asymmetry in returns within the distribution of the fixing returns, the difference in the distribution compared to open markets distribution, the opposing direction of fixing returns with general market direction, and directionally aware preemptive trades.

The intraday underpricing of the commodity has a disproportionate impact on non-financial actors involved in the fundamental commodity trade. Unlike the financial intermediaries, these participants often trade only on the fixing price. Most-directly affected are the metal producers, such as miner and refiners, delivering on long term contracts ("off-take agreements") that are priced on the fixing benchmark. Moreover, this would also impact royalty holders, such as indigenous land owners or private lease holders, who derive royalties based on net smelter revenues. It could also impact governments that derive revenue directly from silver mining through collections on mandated mining royalties and taxes, and indirectly from general income tax, export duties and/or sales taxes.

The second wedge created by the fixing is the information advantage accruing to the fixing participants. During the fixing there are in essence two classes of traders, informed fixing participants and uninformed public market participants. This study provides strong empirical support that fixing participants are trading ahead of the fixing result being published, effectively front-running the result. While the legality of this is debatable, its ethics and desirability are not. It does not make for a level playing field, providing fixing participants an information advantage at a cost to the broader market. Active non-participant

traders at the time of the fixing may have cause for complaint, similar to those who have already filed civil suits in relation to the gold fixing.[26]

Finally, consider the argument that the fixing is a necessary liquidity concentrator, needed to clear fundamental supply and demand. This may well have been true at its inception in 1897. Whether this is still the case is another question. The 2012 global production of silver (including mines and recycling) was 1,048.3 million ounces.[27] This equates to roughly 4,200,000 troy ounces per trade day. With each SI silver future contact covering 5000 ounces for physical delivery, this equates the global daily silver production to around 840 silver future contracts. During the same year, the daily trade volume of the active silver future contracts, during the London trade day, was approximately 30,000 contracts - enough to cover 35 times total production. By December 2013 the CME reported[28] average daily volume at 40,844, enough to cover annual global production in just over one trade week. This is an active market where buyers and sellers have access to deep liquidity and can transact in size, with or without the fixing.

In closing, there is strong evidence to suggest the fixing induces short term price suppression and information asymmetry, neither of which benefits the broader market. Benefits of the fixing appear limited to its members, and possibly *selectively* its non-member participants. For those transaction at the fixing price: buyers are the winners, sellers the losers. While the fixing may have been perfectly 'fit for purpose' at the time of its inception, the value of the silver fixing in the modern global silver market is less clear. Further, this study places in question the fixing's role as an 'objective' price discoverer.

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[26] AIS Capital Management, a commodity trader, files civil law suit against the gold fixing members in March 2013, as reported in
http://online.wsj.com/news/articles/SB10001424052702303795904579432521134011100
[27] For global supply and demand statistics see https://www.silverinstitute.org/site/supply-demand/
[28] http://www.cmegroup.com/trading/metals/files/momu-2013-12.pdf

Any Silver Linings?

There are numerous alternatives to the fixing, and the search for a replacement is well underway[29]. Where transactions are observable, such in the futures markets, the daily settlement prices could offer an alternative. The implementation detail of settlement prices vary greatly, as does their susceptibility to gaming by nefarious market participants. The use of volume weighted average prices (VWAP) of actual trades, as in the CME settlement price procedure, provides some cover. It also raises further implementation questions, such as how long pricing windows should be open. In the case of the CME the window is open for a single minute, whereas the SHFE uses the whole trade day. The exploration of the comparative merits and consequences are left for further research.

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[29] http://online.wsj.com/articles/seven-proposals-made-to-replace-the-london-silver-fix-1403169463

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Table 1
Silver fixing sample data issues summary (2000-2013)

	Observations removed		Observations remaining	
	Records	*Fixings*	*Records*	*Fixings*
Raw Sample	**0**	**0**	**4,420**	**3,519**
Timestamps prior to fixing start	46	7	4,374	3,512
Fixings exceeding one hour	43	24	4,331	3,488
Missing spot market data	5	5	4,326	3,483
Missing futures market data	110	105	4,216	3,378
Final Sample	**204**	**141**	**4,216**	**3,378**

Fixings refers to the number of daily silver fixings from 1 January 2000 through to 31 December 2013. Multiple records per fixing can occur when interim updates are issued during the fixing.

Table 2
Summary Statistics of the London silver fixing (2000-2013)

Panel A - Fixings by Periods (minutes)

	<1	[1-2)	[2-3)	[3-4)	[4-5)	[5-6)	[6-7)	[7-8)	[8-9)	[9-10)	[10-15)	[15-20)	[20-30)	[30-45)	[45-60)	All
n	140	300	645	693	524	353	227	162	114	51	120	18	17	9	5	3378
n%	4	9	19	21	16	10	7	5	3	2	4	1	1	0	0	100
cumm%	4	13	32	53	68	79	85	90	93	95	99	99	100	100	100	
Fix Period Statistics:																
$\bar{T}_{Fix}$	0.5	1.6	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	11.7	16.5	23.7	36.1	49.6	4.6
$Upd\%$	14	38	15	10	9	6	5	4	4	4	6	17	47	78	80	12
$\bar{T}_{Upd}$	0.2	0.4	0.6	1.1	1.6	2.9	3	4.7	5.5	1.7	6.1	7	7.7	8.4	4.4	1.4
$\bar{T}_{1st}$	0.4	1.1	2.2	3.2	4.2	5.3	6.3	7.4	8.3	9.2	11.3	15.1	15.3	14.7	12.5	4.2
Fix Return Statistics:																
$\bar{R}_{Fix}$	-3.3***	-6.2***	-7.8***	-7.8***	-7.3***	-11.5***	-7.7***	-10.2***	-15.7***	- 9.7	-10.2*					-8.3***
$Neg{:}Pos$	2.2***	3.2***	3.5***	2.6***	1.9***	2.4***	1.7***	1.6***	2.3***	1.4	1.2*					2.3***
$Flat\%$	16	12	14	11	10	9	8	7	11	10	6					11
$\bar{R}_P$	5.7	10.1	10.6	11.3	14.7	15.0	16.5	23.7	18.3	23.2	23.8					14.7
$\bar{R}_N$	- 8.4	-12.6	-14.6	-16.4	-20.3	-24.3	-23.1	-31.9	-33.7	-34.6	-40.4					-19.6
$\bar{R}_P{-}\|\bar{R}_N\|$	-2.6*	-2.4*	-4.0***	-5.1***	-5.6***	-9.3***	-6.6**	- 8.2	-15.3**	-11.4	-16.6*					-4.8***

Panel B - Fixings by Year

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	<'07	≥'07	<'12	≥'12
n	225	222	228	233	232	241	243	251	254	250	247	251	249	252	1624	1754	2960	418
Fix Period Statistics:																		
$\bar{T}_{Fix}$	4.4	4.5	4.4	5.2	5.1	4.4	6.3	5.7	5.6	4.4	4.2	6	2.6	2.1	4.9	4.4	5	2.1
$Upd\%$	2	2	1	6	5	3	6	2	3	1	2	15	48	73	4	21	4	72
$\bar{T}_{Upd}$	3.5	3.6	3.6	4.9	6	3.8	7	5.1	4.6	4.4	4.7	2.2	0.4	0.3	5.2	0.8	4.1	0.4
$\bar{T}_{1st}$	4.4	4.4	4.3	5.1	5.1	4.4	5.6	5.2	5	4.3	4.2	5.5	1.6	0.4	4.8	3.7	4.8	0.5
Fix Return Statistics:																		
$\bar{R}_{Fix}$	-12.1***	-13.4***	-12.6***	-8.0***	-6.3***	-5.2***	-9.7***	-3.5***	-16.6***	-11.5***	-0.5	-6.8**	-5.6***	-5.0***	-9.6***	-7.1***	-8.7***	-5.1***
$Neg{:}Pos$	15.5***	7.2***	4.6***	3.0***	1.7***	2.0***	1.9***	1.7***	3.9***	2.8***	1.1	1.2**	2.6***	1.6***	3.1***	1.9***	2.4***	2.0***
$Flat\%$	20	19	14	22	13	17	7	9	4	7	6	5	5	7	16	6	11	7
$\bar{R}_P$	17.9	15.2	14.9	15.9	18.1	13.5	16.2	10.9	18.7	14.6	12.2	19.2	10.3	13	15.9	14.1	15.1	12.5
$\bar{R}_N$	-17.2	-21	-21.3	-18.9	-22.1	-16.2	-24.1	-12.3	-26.5	-22.1	-12.4	-29.1	-12.1	-16.9	-20.1	-19.1	-20.3	-14.7
$\bar{R}_P{-}\|\bar{R}_N\|$	0.7	-5.8*	-6.3**	-3	-4	-2.7	-7.8*	-1.4	-7.8	-7.5*	-0.2	-9.9**	-1.8	-3.9	-4.2***	-5.0***	-5.1***	-2.2

Presented are statics on the time taken for the silver fixing to complete (the fix period) and the return in spot silver over this periods (the fix return). Panel A presents summary statistics of fixings grouped by the fixing period. Column "<1" report the fixings completed in under one minute, while column "[1-2)" contains fixings with periods between one to two minutes, inclusive of one minute fixings and exclusive of 2 minutes fixings. Column "All" presents the statistics for the full sample. Panel B reports the statistics grouped the fixings year. The "<'07" and "≥'07" columns break out the sample pre and post January 1, 2007. The "<'12" and "≥'12" columns break out the sample pre and post May 1, 2012. In each Panel, $\bar{T}_{Fix}$ reports the average period between the fixing start and the fixing end, $\bar{T}_{1st}$ reports the average period to the 1st public price from the fixing, $Upd\%$ reports the percentage of fixings for which an update price was published before the fixing ended, and $\bar{T}_{Upd}$ reports the average time to the first update. All periods are presented in minutes. $\bar{R}_{Fix}$ reports the average fix return, where R_{Fix} is natural logarithm of the ratio of the spot mid-point price immediately before the fixing and the final published fixing price. *,** and *** denote 5%,1% and 0.1% significance for a two-side t-test of $\bar{R}_{Fix}$ = 0. The ratio of negative to positive fixing returns is given by $Neg{:}Pos$, with values above one indicating a higher incidence of negative returns. *,** and *** denote 5%,1% and 0.1% significance for a proportion z-test of $Neg{:}Pos$ = 1. $Flat\%$ reports the percentage of fixings for there was no price change, ie. R_{Fix} = 0. $\bar{R}_N$ ($\bar{R}_P$) is the average fix returns of only the negative (positive) days. $\bar{R}_P{-}\|\bar{R}_N\|$ reports the difference between the two average returns, and *,** and *** denote 5%,1% and 0.1% significance for a two-side t-test of $\bar{R}_P{-}\|\bar{R}_N\|$ = 0. All returns are presented in basis points. The sample period covers 3378 fixings from January 1, 2000 to December 31, 2013.

Table 3

Comparison of silver return distributions (2000-2013)

	Panel A - Comparison of Fixing and Spot Returns Distributions				
	Full Sample	*Pre 2007*	*Post 1-Jan-2007*		
			All	*Pre May-2012*	*Post May-2012*
n	3378	1624	1754	1336	418
KS	0.29***	0.49***	0.11***	0.10***	0.16***
p-value	0.000	0.000	0.000	0.000	0.000
	Panel B - Comparison of Fixing and Futures Returns Distributions				
	Full Sample	*Pre 2007*	*Post 1-Jan-2007*		
			All	*Pre May-2012*	*Post May-2012*
n	3378	1624	1754	1336	418
KS	0.26***	0.41***	0.12***	0.11***	0.17***
p-value	0.000	0.000	0.000	0.000	0.000
	Panel C - Comparison of Spot and Futures Returns Distributions				
	Full Sample	*Pre 2007*	*Post 1-Jan-2007*		
			All	*Pre 1-May-2012*	*Post 1-May-2012*
N	3378	1624	1754	1336	418
KS	0.11***	0.18***	0.05*	0.04	0.07
p-value	0.000	0.000	0.028	0.132	0.296

The table summarizes the comparison of the distribution of three returns during the fix period. Panel A shows the comparison between the fix returns (R_{Fix}) and spot returns (R_{Spt}). Panel B compares R_{Fix} and future returns (R_{Fut}), and Panel C comparing R_{Fut} and R_{Spt} returns. In each panel, results are provided for the full sample period (2000-2013), pre and post the introduction of electronic futures trading in 2007, with the post 2007 sub-sample, is further broken into pre and post the structural break of May 2012. The Kolmogorov–Smirnov (**KS**) statistic test, and associated p-value, for inequality of two empirical distributions is reported for the full sample and each sub-sample. A low p-value indicates a high degree of confidence that the null hypothesis of inequality can be rejected. *,** and *** indicate significance of 5%, 1% and 0.1% respectively. The samples covers 3,378 fixings from 1st January 2000 through to 31st December 2013.

Table 4
Trade volumes of silver futures (SI) around the time of the London silver fixing (2000-2013)

		Panel A: 2000-2006											Panel B: 2007-2013										
		t_0 = Start of fixing					t_0 = End of fixing					t_0 = Start of fixing					t_0 = End of fixing					
		VMi Statistics			t-Tests		VMi Statistics			t-Tests		VMi Statistics			t-Tests		VMi Statistics			t-Tests	
i	t_i	$\overline{VM}_i$	P50	SD	$\overline{VM}$	$\overline{\Delta VM}$	$\overline{VM}_i$	P50	SD	$\overline{VM}$	$\overline{\Delta VM}$	$\overline{VM}_i$	P50	SD	$\overline{VM}$	$\overline{\Delta VM}$	$\overline{VM}_i$	P50	SD	$\overline{VM}$	$\overline{\Delta VM}$
-14	11:46	1.3	0.0	6.9	0.1	-1.0	1.4	0.0	5.9	-3.2	-5.2	15.5	7.0	28.5	1.9 *	4.2 **	17.1	7.0	34.8	-7.8	-11.4
-13	11:47	1.3	0.0	6.4	0.1	-0.9	1.4	0.0	6.5	-2.8	-5.5	15.5	6.0	31.5	1.6	1.8 *	17.4	7.0	33.7	-7.4	-11.1
-12	11:48	1.2	0.0	5.5	-0.9	-1.1	1.3	0.0	5.9	-3.8	-4.8	16.1	6.0	30.6	2.6 **	3.8 **	17.6	7.0	37.1	-6.7	-11.8
-11	11:49	1.1	0.0	4.8	-1.3	-0.9	1.2	0.0	4.9	-4.5	-4.8	15.6	7.0	29.2	1.9 *	3.8 **	18.6	8.0	34.7	-5.8	-8.5
-10	11:50	1.2	0.0	6.1	-0.5	-0.4	1.2	0.0	4.3	-5.6	-5.4	17.2	7.0	52.6	2.3 *	4.2 **	18.9	8.0	34.8	-5.4	-9.0
-9	11:51	1.3	0.0	5.9	0.5	1.5	1.5	0.0	6.3	-2.2	-4.9	18.7	8.0	35.8	5.4 **	8.6 **	20.4	8.0	43.8	-3.3	-7.7
-8	11:52	1.2	0.0	5.7	-0.4	-0.7	1.7	0.0	7.6	-0.6	-3.6	18.6	8.0	41.5	4.3 **	6.8 **	19.7	9.0	32.2	-5.0	-6.3
-7	11:53	1.5	0.0	6.1	1.3	2.2 *	1.3	0.0	5.7	-3.3	-4.9	18.0	7.0	32.9	4.9 **	7.0 **	22.0	10.0	43.5	-1.9	-3.9
-6	11:54	1.2	0.0	6.2	-0.2	-1.3	1.5	0.0	5.8	-2.1	-2.5	18.4	8.0	38.8	4.6 **	7.3 **	23.7	10.0	45.0	-0.3	-3.3
-5	11:55	1.3	0.0	5.2	-0.1	0.2	1.8	0.0	6.4	-0.2	-0.3	18.1	8.0	31.7	5.1 **	7.1 **	24.6	10.0	44.3	0.5	-2.7
-4	11:56	1.1	0.0	3.9	-1.9	0.5	2.0	0.0	7.1	0.8	-0.6	18.4	8.0	37.1	5.0 **	9.6 **	28.4	12.0	47.8	3.9 **	2.5 **
-3	11:57	1.2	0.0	4.8	-0.7	0.5	2.1	0.0	6.7	1.5	2.3 *	18.7	9.0	29.6	6.5 **	10.5 **	31.5	15.0	48.1	6.6 **	6.5 **
-2	11:58	1.3	0.0	5.3	0.1	-0.6	2.4	0.0	7.7	3.1 **	3.0 **	18.5	9.0	33.2	5.8 **	10.8 **	35.8	19.0	51.6	9.8 **	14.1 **
-1	11:59	1.5	0.0	6.8	1.5	1.3	2.1	0.0	6.5	1.4	2.7 **	22.4	10.5	43.5	8.0 **	12.6 **	39.9	23.0	52.9	12.7 **	17.7 **
0	**12:00**	**1.3**	**0.0**	**6.4**	**0.4**	**0.6**	**2.5**	**0.0**	**7.7**	**3.1 ****	**4.3 ****	**26.5**	**13.0**	**41.3**	**12.8 ****	**21.7 ****	**39.6**	**24.0**	**49.6**	**13.4 ****	**20.3 ****
1	12:01	1.8	0.0	6.2	3.2 **	4.9 **	1.6	0.0	5.7	-1.5	-0.7	47.4	30.0	57.9	25.2 **	41.4 **	39.6	25.0	47.5	13.8 **	19.7 **
2	12:02	3.1	0.0	7.9	9.2 **	12.4 **	1.6	0.0	5.6	-1.9	-1.1	53.4	36.5	58.8	29.8 **	49.1 **	36.6	23.0	45.4	11.7 **	19.1 **
3	12:03	2.7	0.0	8.1	6.8 **	9.2 **	1.7	0.0	5.6	-1.3	-0.4	44.3	29.0	51.5	26.5 **	46.4 **	31.9	19.0	45.0	7.3 **	15.0 **
4	12:04	2.2	0.0	6.9	5.5 **	8.5 **	1.7	0.0	6.2	-0.9	0.5	36.3	23.0	43.6	22.8 **	39.3 **	29.0	18.0	38.3	5.4 **	12.3 **
5	12:05	2.4	0.0	8.2	5.6 **	8.4 **	1.6	0.0	4.7	-2.4	0.5	33.8	20.0	47.4	18.7 **	34.5 **	27.6	16.0	38.2	3.7 **	8.8 **
6	12:06	2.0	0.0	6.8	4.8 **	7.1 **	1.6	0.0	5.9	-1.6	-1.5	33.5	20.0	48.6	18.2 **	34.5 **	26.1	15.0	37.7	2.1 *	6.1 **
7	12:07	1.9	0.0	6.7	3.5 **	6.2 **	2.0	0.0	9.2	0.8	1.9 *	30.1	17.0	44.7	16.3 **	33.0 **	24.5	13.0	42.6	0.5	3.6 **
8	12:08	1.6	0.0	5.6	2.1 *	5.4 **	2.0	0.0	8.2	1.0	0.4	28.7	16.0	47.7	13.2 **	27.3 **	23.8	13.0	40.7	-0.2	3.6 **
9	12:09	1.5	0.0	5.4	1.8 *	5.1 **	1.7	0.0	6.1	-0.9	-0.3	27.1	15.0	41.4	14.1 **	24.4 **	22.2	12.0	33.7	-2.2	0.9
10	12:10	1.9	0.0	6.2	4.0 **	6.6 **	1.6	0.0	5.3	-2.0	-0.9	24.9	13.0	42.7	10.9 **	22.1 **	23.6	12.0	57.0	-0.3	0.8
11	12:11	2.0	0.0	9.2	3.2 **	5.3 **	1.7	0.0	7.6	-0.6	-1.8	24.5	14.0	37.6	11.7 **	22.8 **	22.0	11.0	38.0	-2.3	-0.2
12	12:12	1.8	0.0	7.1	2.9 **	5.2 **	1.6	0.0	5.6	-2.0	-0.8	22.4	12.0	37.6	9.3 **	18.5 **	21.6	11.0	38.8	-2.6	0.3
13	12:13	1.6	0.0	5.9	2.4 **	4.3 **	1.8	0.0	6.3	-0.4	-0.9	24.1	12.0	54.6	7.7 **	19.7 **	20.1	11.0	30.8	-4.9	-2.0
14	12:14	1.8	0.0	7.8	2.6 **	3.7 **	2.1	0.0	8.2	1.4	1.3	22.1	11.0	44.0	7.5 **	17.7 **	21.5	11.0	43.0	-2.6	-1.0
15	12:15	1.6	0.0	6.1	2.2 *	4.0 **	1.8	0.0	6.4	0.0	0.2	22.0	11.0	38.0	8.8 **	18.7 **	21.3	10.0	37.2	-3.2	-2.2

For each one minute interval (**i**) the average volume ($\overline{VM}_i$), median volume (**P50**) and the sample standard deviation (**SD**) across the sample is reported. The t-statistic for the one-sided paired t-test of $\overline{VM}_i > VM_{Ref}$ ($\overline{VM}$) and one-sided t-test of of $\overline{\Delta VM}_i > 0$ ($\overline{\Delta VM}$) are also presented, with *,** denoting significance at 5%, 1%. **VM_Ref** is the reference level of volume calculated by averaging across 15 minutes. For intervals aligned to the start of the fixing **(t₀ = Start of Fixing)**, interval i=0 represents the last one minute interval before the start of the fixing and the reference period covers 11:30am through to 11:45am (London). For intervals aligned to the end of the fixing **(t₀ = End of Fixing)**, interval i=0 represents last one minute interval before the end of the fixing and the reference period covers the 15 to 30 minutes following the end of the fixing. The last interval before the start / end of the fixing is bolded for emphasis. The sample period covers January 1, 2000 to December 31, 2013, split between Panel A and Panel B containing 1,624 and 1,754 fixing samples respectively.

Table 5
Price volatility of spot silver (XAG) around the time of the London silver fixing

		Panel A: 2000-2006										Panel B: 2007-2013									
		t_0 = Start of fixing					t_0 = End of fixing					t_0 = Start of fixing					t_0 = End of fixing				
		Vi Statistics			t-Tests		Vi Statistics			t-Tests		Vi Statistics			t-Tests		Vi Statistics			t-Tests	
i	t_i	$\overline{V}_i$	P_{50}	SD	$\overline{V}$	$\overline{\Delta V}$	$\overline{V}_i$	P_{50}	SD	$\overline{V}$	$\overline{\Delta V}$	$\overline{V}_i$	P_{50}	SD	$\overline{V}$	$\overline{\Delta V}$	$\overline{V}_i$	P_{50}	SD	$\overline{V}$	$\overline{\Delta V}$
-14	11:46	0.4	0.0	2.1	-2.1	-1.4	0.4	0.0	2.2	-2.9	-3.7	5.6	4.9	4.8	-0.1	-0.3	5.7	4.9	4.7	-6.6	-5.9
-13	11:47	0.5	0.0	2.4	-0.6	-0.6	0.4	0.0	2.2	-2.5	-3.0	5.8	5.1	5.0	1.7 *	2.1 *	5.8	5.0	5.0	-5.0	-5.0
-12	11:48	0.4	0.0	2.2	-2.2	-1.9	0.5	0.0	2.2	-1.8	-2.3	5.9	5.3	4.9	3.3 **	3.8 **	5.9	5.1	5.0	-4.0	-4.2
-11	11:49	0.5	0.0	2.4	-0.2	0.4	0.5	0.0	2.8	-0.4	-1.4	5.7	5.1	5.1	1.5	0.4	5.9	5.2	5.1	-3.1	-3.4
-10	11:50	0.5	0.0	3.0	-0.3	-0.6	0.6	0.0	3.6	0.7	-0.7	5.6	4.8	4.8	0.3	0.3	5.9	5.2	5.1	-3.3	-3.5
-9	11:51	0.5	0.0	2.3	-1.2	-0.5	0.4	0.0	2.1	-2.4	-2.6	5.8	4.9	5.1	1.8 *	1.0	6.0	5.2	5.2	-3.1	-4.1
-8	11:52	0.6	0.0	3.1	0.4	0.0	0.6	0.0	3.0	-0.3	-1.2	6.1	5.3	5.3	5.1 **	5.3 **	6.0	5.2	5.3	-2.4	-3.8
-7	11:53	0.5	0.0	2.4	-1.2	-1.0	0.4	0.0	1.9	-4.3	-4.6	5.8	5.3	4.9	2.6 **	2.3 *	6.1	5.4	5.0	-2.0	-2.3
-6	11:54	0.5	0.0	2.3	-0.8	-0.2	0.5	0.0	3.0	-0.5	-1.4	5.8	5.1	4.9	2.7 **	2.6 **	6.3	5.6	5.3	0.0	-0.4
-5	11:55	0.4	0.0	2.1	-2.9	-2.1	0.5	0.0	2.1	-1.3	-0.8	5.9	5.0	5.0	2.9 **	2.8 **	6.2	5.5	5.7	-0.1	-1.3
-4	11:56	0.4	0.0	2.5	-1.8	-1.9	0.7	0.0	4.6	0.9	0.4	5.8	5.0	5.0	2.6 **	2.0 *	6.5	5.6	5.8	2.2 *	0.6
-3	11:57	0.4	0.0	2.6	-1.8	-2.3	0.5	0.0	2.2	-1.4	-1.1	6.0	5.4	4.8	4.4 **	4.9 **	6.6	5.8	5.9	3.6 **	2.7 **
-2	11:58	0.5	0.0	3.0	-0.2	-0.1	0.6	0.0	4.8	0.5	0.0	6.0	5.5	5.0	4.5 **	4.7 **	6.9	6.1	5.4	6.8 **	7.2 **
-1	11:59	0.5	0.0	3.1	-0.3	-0.9	0.8	0.0	5.0	1.9 *	2.7 **	6.0	5.4	5.0	4.0 **	4.4 **	7.0	6.2	5.4	8.1 **	8.6 **
0	**12:00**	**0.5**	**0.0**	**2.2**	**-1.8**	**-1.2**	**0.8**	**0.0**	**3.0**	**2.8 ****	**3.0 ****	**6.2**	**5.5**	**5.1**	**6.8 ****	**6.5 ****	**7.1**	**6.2**	**5.3**	**8.7 ****	**9.4 ****
1	12:01	0.4	0.0	2.8	-2.8	-4.4	0.7	0.0	2.6	1.7 *	2.4 **	7.2	6.4	5.7	15.1 **	16.3 **	6.8	6.0	5.4	5.3 **	5.2 **
2	12:02	0.6	0.0	2.4	1.0	2.1 *	0.7	0.0	2.6	1.6	2.2 *	7.8	6.9	6.2	18.4 **	23.0 **	6.6	5.8	5.4	3.8 **	3.2 **
3	12:03	0.6	0.0	2.3	1.6 *	3.5 **	0.6	0.0	2.6	0.8	1.0	7.3	6.4	5.5	16.8 **	19.3 **	6.4	5.5	5.2	1.5	0.9
4	12:04	0.8	0.0	2.8	4.3 **	6.0 **	0.7	0.0	3.0	2.3 **	2.5 **	6.8	6.0	5.5	11.5 **	13.0 **	6.4	5.7	5.0	1.0	1.0
5	12:05	0.8	0.0	5.0	2.3 *	4.0 **	0.7	0.0	3.2	2.1 *	2.6 **	6.6	5.7	5.3	10.5 **	10.9 **	6.4	5.6	5.1	1.3	1.6
6	12:06	0.8	0.0	5.2	2.4 **	3.7 **	0.7	0.0	2.5	2.1 *	2.9 **	6.5	5.4	5.7	8.6 **	8.2 **	6.3	5.5	5.2	0.7	0.5
7	12:07	0.7	0.0	2.5	2.9 **	4.6 **	0.6	0.0	2.7	1.0	1.2	6.6	5.8	5.1	10.4 **	11.4 **	6.2	5.2	5.2	-0.9	-1.6
8	12:08	0.9	0.0	4.9	2.9 **	4.9 **	0.6	0.0	2.5	0.1	0.2	6.5	5.8	5.4	9.4 **	10.1 **	6.2	5.5	5.3	-0.2	-0.6
9	12:09	0.7	0.0	2.6	2.3 *	3.4 **	0.6	0.0	2.5	0.1	0.2	6.3	5.4	5.3	7.4 **	6.7 **	6.2	5.5	5.3	-0.3	-0.6
10	12:10	0.7	0.0	2.6	2.0 *	3.2 **	0.6	0.0	2.5	-0.1	-0.5	6.3	5.3	5.7	6.4 **	5.3 **	6.1	5.4	5.3	-1.5	-1.8
11	12:11	0.5	0.0	2.3	-0.1	1.2	0.5	0.0	2.3	-0.7	-0.5	6.2	5.4	5.4	6.2 **	6.1 **	6.0	5.4	5.0	-2.4	-2.0
12	12:12	0.8	0.0	3.3	2.9 **	4.0 **	0.8	0.0	3.1	2.5 **	2.3 *	6.2	5.5	5.1	6.6 **	7.1 **	6.1	5.2	5.2	-1.2	-1.6
13	12:13	0.6	0.0	2.5	0.2	0.9	0.6	0.0	2.6	-0.2	-0.4	6.2	5.5	5.1	6.5 **	6.7 **	5.9	5.1	5.1	-3.7	-3.9
14	12:14	0.5	0.0	2.1	-0.8	0.5	0.6	0.0	2.5	-0.4	-0.6	6.0	5.3	4.9	4.8 **	5.1 **	6.0	5.2	5.1	-2.4	-2.8
15	12:15	0.7	0.0	2.8	1.4	2.0 *	0.6	0.0	2.9	0.5	-0.2	6.0	5.3	5.1	4.6 **	4.1 **	6.2	5.4	5.1	-1.2	-1.5

For each one minute interval (**i**) the average volatility ($\overline{V}_i$), median volatility (**P_{50}**) and the sample standard deviation (**SD**) across the sample is reported. The t-statistic for the one-sided paired t-test of $\overline{V}_i > V_{Ref}$ ($\overline{V}$) and one-sided t-test of $\overline{\Delta V}_i > 0$ ($\overline{\Delta V}$) are also presented, with *,** denoting significance at 5%, 1%. **V_{Ref}** is the reference level of price volatility calculated by averaging across 15 minutes. For intervals aligned to the start of the fixing **(t_0 = Start of Fixing)**, interval i=0 represents the last one minute interval before the start of the fixing and the reference period covers 11:30am through to 11:45am (London). For intervals aligned to the end of the fixing **(t_0 = End of Fixing)**, interval i=0 represents last one minute interval before the end of the fixing and the reference period covers the 15 to 30 minutes following the end of the fixing. The last interval before the start / end of the fixing is bolded for emphasis. The sample period covers January 1, 2000 to December 31, 2013, split between Panel A and Panel B containing 1,624 and 1,754 fixing samples respectively.

Table 6

Returns on Spot Silver (XAG) around the time of the London Silver Fixing (2000-2013)

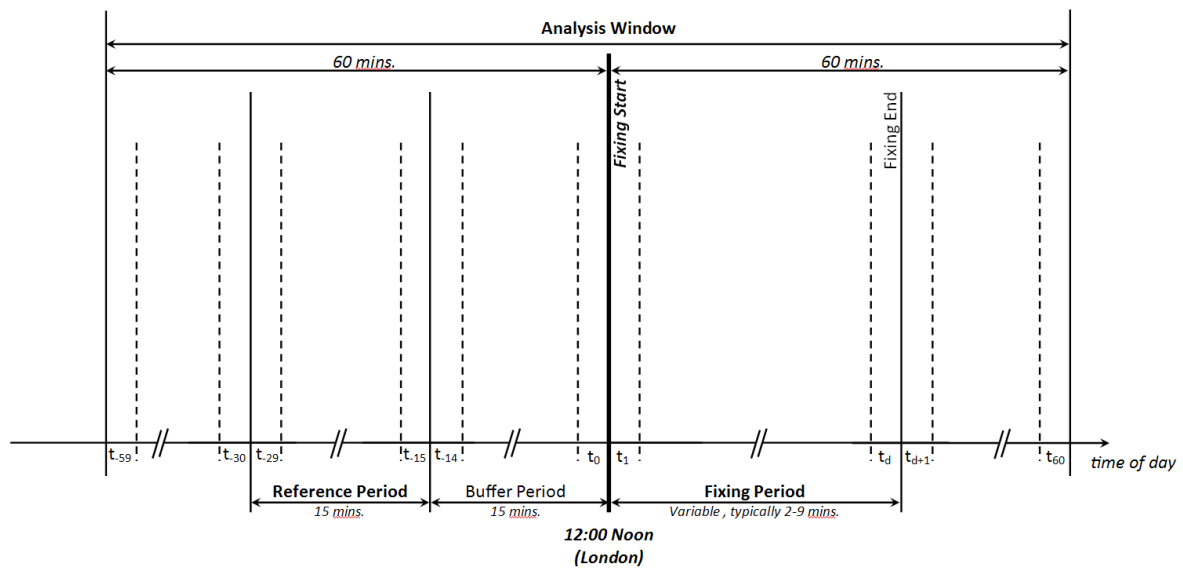|		Panel A: 2000-2006						Panel B: 2007-2013					
		t_0 = Start of fixing			t_0 = End of fixing			t_0 = Start of fixing			t_0 = End of fixing		
i	t_i	$\overline{UR_i}$	$\overline{AR_i}$	$\overline{DR_i}$	$\overline{UR_i}$	$\overline{AR_i}$	$\overline{DR_i}$	$\overline{UR_i}$	$\overline{AR_i}$	$\overline{DR_i}$	$\overline{UR_i}$	$\overline{AR_i}$	$\overline{DR_i}$
-14	11:46	-0.2	0.0	0.2	-0.2 *	0.1	0.3 *	-0.2	0.1	0.2	0.0	0.2	0.2
-13	11:47	-0.1	0.1	0.2	-0.1	0.1	0.3	-0.3	0.2	0.5	-0.4 *	0.5 **	0.9 ***
-12	11:48	0.2	-0.2	-0.4	0.0	-0.1	-0.1	0.2	0.2	0.0	0.0	0.2	0.2
-11	11:49	-0.3 *	0.0	0.3	-0.2	0.2	0.3	-0.4	-0.1	0.3	-0.6 ***	0.1	0.7 *
-10	11:50	-0.5 *	0.1	0.6 **	0.0	0.2	0.2	0.0	0.3 *	0.3	-0.3	0.5 **	0.8 **
-9	11:51	-0.1	-0.2 *	-0.2	-0.1	0.0	0.1	-0.3	0.5 *	0.8 *	-0.3	0.2	0.5
-8	11:52	0.2	0.1	-0.1	-0.2	-0.1	0.1	0.0	0.2	0.2	-0.3	0.3	0.6 *
-7	11:53	-0.1	0.1	0.1	-0.1	0.1	0.3	-0.2	0.2	0.5	-0.6 **	0.8 ***	1.4 ***
-6	11:54	-0.3 *	0.0	0.4	-0.2	0.3	0.4 *	-0.4 *	0.2	0.6 *	-0.7 **	0.6 **	1.2 ***
-5	11:55	-0.2	0.1	0.3	-0.3 *	0.3 **	0.6 **	-0.4 *	0.5 **	0.9 **	-0.5 *	0.9 ***	1.4 ***
-4	11:56	0.0	0.0	0.0	-0.2	0.3 *	0.5 *	-0.6 **	0.4 *	0.9 **	-1.2 ***	1.7 ***	2.9 ***
-3	11:57	0.0	0.0	0.0	-0.3 *	0.4 ***	0.6 ***	-0.5 **	0.3	0.7 **	-0.8 ***	1.5 ***	2.3 ***
-2	11:58	-0.2	0.0	0.2	-0.6	0.8 *	1.4 *	-0.5 **	0.1	0.6 *	-0.8 ***	1.9 ***	2.7 ***
-1	11:59	-0.1	-0.3 *	-0.2	0.2	0.9 *	0.6	-0.6 **	0.3	0.9 **	-1.0 ***	2.1 ***	3.1 ***
0	**12:00**	**-0.1**	**0.0**	**0.1**	**0.0**	**0.9 *****	**1.0 *****	**-1.0 *****	**0.2**	**1.1 *****	**-0.4 ***	**1.4 *****	**1.9 *****
1	12:01	0.0	0.6 ***	0.6 ***	-0.2	0.7 ***	0.9 ***	-1.3 ***	3.3 ***	4.6 ***	-0.8 ***	1.0 ***	1.8 ***
2	12:02	-0.5 ***	1.0 ***	1.5 ***	0.0	0.5 **	0.4	-1.4 ***	4.3 ***	5.8 ***	-0.6 **	0.4 *	1.0 **
3	12:03	-0.2	1.1 ***	1.3 ***	0.2	0.3 *	0.1	-0.6 *	2.1 ***	2.6 ***	0.2	0.1	-0.1
4	12:04	-0.4 *	1.2 ***	1.6 ***	-0.4 *	0.6 ***	0.9 ***	-0.6 **	0.6 ***	1.2 ***	0.6 ***	0.0	-0.7 *
5	12:05	-0.4	1.0 **	1.4 *	0.1	0.3	0.1	-0.3	0.7 ***	1.0 **	-0.1	0.0	0.1
6	12:06	0.7	0.5	-0.1	0.0	0.6 ***	0.6 *	0.0	0.5 *	0.5	0.4 *	0.0	-0.4
7	12:07	0.2	0.6 ***	0.4	0.3 *	0.2	-0.1	-0.1	0.3	0.4	0.4	-0.2	-0.6
8	12:08	0.0	0.4 *	0.4	0.0	0.1	0.1	0.2	-0.2	-0.4	-0.1	-0.3	-0.2
9	12:09	0.2	0.5 **	0.2	0.0	0.1	0.2	0.3	-0.1	-0.5	0.2	0.0	-0.2
10	12:10	0.0	0.4 **	0.4	0.2	0.3	0.0	0.5 *	-0.1	-0.6	0.1	-0.4 *	-0.5
11	12:11	0.0	0.3 *	0.3	0.2	0.0	-0.2	0.0	-0.1	-0.1	0.0	0.0	0.0
12	12:12	-0.4 *	0.4 **	0.8 **	0.1	0.1	0.0	0.2	-0.1	-0.3	0.1	0.2	0.1
13	12:13	0.3 *	0.2	-0.1	0.1	0.1	-0.1	-0.2	0.2	0.4	0.1	0.0	-0.1
14	12:14	0.2	-0.1	-0.3	-0.3	0.3	0.6 *	0.1	-0.1	-0.2	0.2	0.0	-0.3
15	12:15	0.1	0.2	0.1	0.1	0.1	0.1	0.0	-0.3	-0.2	0.3	-0.2	-0.5

Average unadjusted returns ($\overline{UR_i}$), adjusted returns ($\overline{AR_i}$) and difference in returns ($\overline{DR_i}$) are log returns presented in basis points (bps). $\overline{UR_i} = 1/N \cdot \sum_{d=1}^{N} ln(C_{i,d}/C_{i-1,d})$ where $C_{i,d}$ is the quote mid-point price at the close of interval *i* on day *d*. $\overline{AR_i} = 1/N \cdot \sum_{d=1}^{N} FIXDIR_d \cdot ln(C_{i,d}/C_{i-1,d})$ and represents the returns achieved by a trader informed as to the future fixing price direction. $FIXDIR_d$ is a dummy set to +1, 0 and -1 depending on the fixing price being greater than, equal to or less than the spot price immediately before the start of the fixing. $\overline{DR_i} = \overline{AR_i} - \overline{UR_i}$ and represents the difference in returns between a directionally informed trader and an uninformed long position. For intervals aligned to the start of the fixing **(t₀ = Start of Fixing)**, interval i=0 represents the last one minute interval before the start of the fixing. For intervals aligned to the end of the fixing **(t₀ = End of Fixing)**, interval *i=0* represents last one minute interval before the end of the fixing. The last interval before the start / end of the fixing is bolded for emphasis. The sample period covers January 1, 2000 to December 31, 2013, split between Panel A and Panel B containing 1,624 and 1,754 fixing samples respectively. *,** and *** denoting significance at 5%, 1% and 0.1% of two-tailed t-test for $\overline{xR_i}$= 0.

Table 7

Cumulative returns on Silver Futures (SI) around the time of the London Silver Fixing (2000-2013)

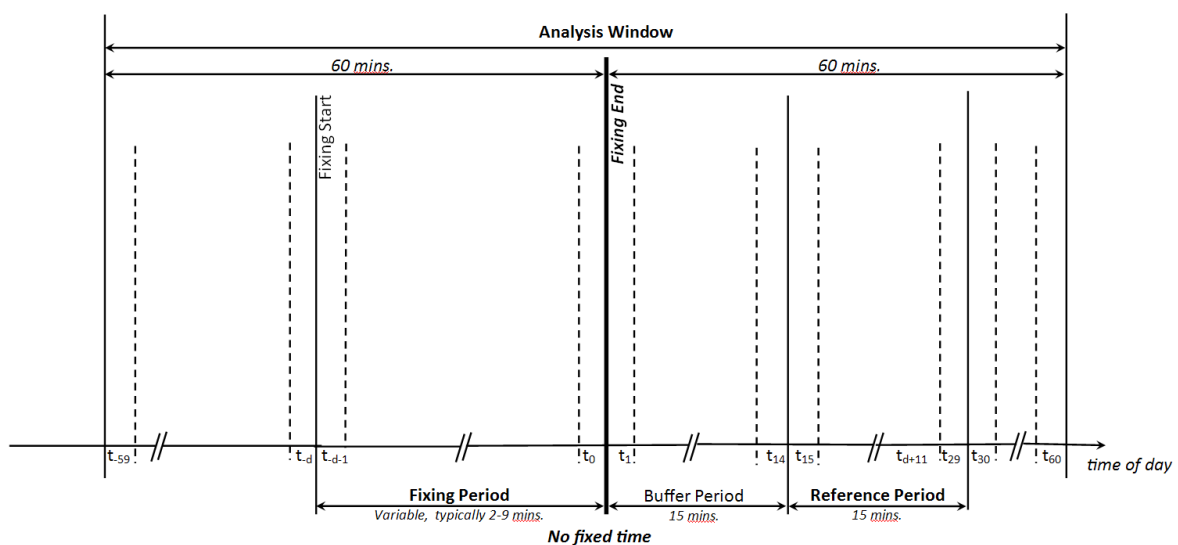|		Panel A: 2000-2006						Panel B: 2007-2013					
		t_0 = Start of fixing			t_0 = End of fixing			t_0 = Start of fixing			t_0 = End of fixing		
i	t_i	$\overline{CUR_i}$	$\overline{CAR_i}$	$\overline{CDR_i}$	$\overline{CUR_i}$	$\overline{CAR_i}$	$\overline{CDR_i}$	$\overline{CUR_i}$	$\overline{CAR_i}$	$\overline{CDR_i}$	$\overline{CUR_i}$	$\overline{CAR_i}$	$\overline{CDR_i}$
-14	11:46	1.7	0.3	-1.4	2.1	-4.3	-6.5	4.8	-3.4	-8.2	7.8	-12.9	-20.7
-13	11:47	1.6	0.4	-1.2	2.0	-4.2	-6.2	4.5	-3.2	-7.7	7.4	-12.4	-19.8
-12	11:48	1.8	0.2	-1.6	2.0	-4.3	-6.3	4.8	-3.0	-7.8	7.5	-12.1	-19.6
-11	11:49	1.5	0.2	-1.3	1.8	-4.1	-5.9	4.4	-3.1	-7.5	6.9	-12.0	-18.9
-10	11:50	1.0	0.3	-0.7	1.8	-4.0	-5.7	4.4	-2.8	-7.2	6.6	-11.5	-18.1
-9	11:51	0.9	0.1	-0.8	1.7	-3.9	-5.6	4.1	-2.3	-6.4	6.3	-11.3	-17.6
-8	11:52	1.1	0.2	-0.9	1.5	-4.0	-5.5	4.1	-2.1	-6.2	6.0	-10.9	-16.9
-7	11:53	1.0	0.2	-0.8	1.4	-3.9	-5.2	3.9	-1.9	-5.8	5.4	-10.1	-15.5
-6	11:54	0.7	0.3	-0.4	1.2	-3.6	-4.8	3.5	-1.6	-5.1	4.7	-9.6	-14.3
-5	11:55	0.5	0.4	-0.1	0.9	-3.3	-4.2	3.1	-1.2	-4.3	4.3	-8.7	-12.9
-4	11:56	0.5	0.4	-0.1	0.7	-3.0	-3.7	2.5	-0.8	-3.3	3.0	-7.0	-10.0
-3	11:57	0.5	0.4	-0.1	0.4	-2.6	-3.0	2.0	-0.6	-2.6	2.2	-5.4	-7.7
-2	11:58	0.2	0.3	0.1	-0.2	-1.8	-1.6	1.5	-0.5	-2.0	1.5	-3.5	-5.0
-1	11:59	0.1	0.0	-0.1	0.0	-0.9	-1.0	1.0	-0.2	-1.1	0.4	-1.4	-1.9
0	**12:00**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
1	12:01	0.0	0.6	0.6	-0.2	0.7	0.9	-1.3	3.3	4.6	-0.8	1.0	1.8
2	12:02	-0.6	1.5	2.1	-0.2	1.1	1.3	-2.7	7.7	10.4	-1.4	1.4	2.8
3	12:03	-0.8	2.6	3.4	0.0	1.4	1.4	-3.3	9.7	13.1	-1.1	1.5	2.6
4	12:04	-1.2	3.8	5.0	-0.4	2.0	2.3	-3.9	10.4	14.3	-0.5	1.4	2.0
5	12:05	-1.6	4.8	6.5	-0.3	2.2	2.5	-4.2	11.1	15.3	-0.6	1.4	2.1
6	12:06	-1.0	5.4	6.3	-0.3	2.8	3.1	-4.2	11.6	15.7	-0.2	1.4	1.6
7	12:07	-0.8	5.9	6.7	0.0	3.0	3.0	-4.3	11.9	16.1	0.2	1.2	1.1
8	12:08	-0.8	6.3	7.2	-0.1	3.1	3.1	-4.0	11.6	15.7	0.1	0.9	0.8
9	12:09	-0.6	6.8	7.4	-0.1	3.2	3.3	-3.7	11.5	15.2	0.3	0.9	0.6
10	12:10	-0.6	7.2	7.8	0.1	3.5	3.3	-3.2	11.4	14.6	0.4	0.5	0.1
11	12:11	-0.6	7.5	8.1	0.3	3.4	3.1	-3.2	11.3	14.6	0.5	0.5	0.1
12	12:12	-1.0	7.9	8.9	0.4	3.5	3.1	-3.0	11.3	14.3	0.5	0.7	0.2
13	12:13	-0.7	8.1	8.7	0.5	3.6	3.1	-3.2	11.5	14.7	0.7	0.7	0.1
14	12:14	-0.5	8.0	8.5	0.2	3.9	3.6	-3.1	11.4	14.5	0.9	0.7	-0.2
15	12:15	-0.4	8.2	8.6	0.3	4.0	3.7	-3.2	11.1	14.3	1.2	0.5	-0.7

Cumulative average unadjusted returns ($\overline{CUR_i}$), adjusted returns ($\overline{CAR_i}$) and difference in returns ($\overline{CDR_i}$) are log returns presented in basis points (bps) and are zeroed at i=0. $\overline{CUR_i}$ represents the return on holding a long position from interval 0 to interval *i*. $\overline{CAR_i}$ represents the return a directionally informed trader can capture over the same period. $\overline{CDR_i}$ = $\overline{CAR_i}$ - $\overline{CUR_i}$ and represents the difference in returns between a directionally informed trader and an uninformed long position. For intervals aligned to the start of the fixing (**t₀ = Start of Fixing**), interval i=0 represents the last one minute interval before the start of the fixing. For intervals aligned to the end of the fixing (**t₀ = End of Fixing**), interval *i=0* represents last one minute interval before the end of the fixing. The last interval before the start / end of the fixing is bolded for emphasis. The sample period covers January 1, 2000 to December 31, 2013, split between Panel A and Panel B containing 1,624 and 1,754 fixing samples respectively.

Table 8
Predictability of the fixing price direction from market returns (2000-2013)

			Panel A: 2000-2006								Panel B: 2007-2013							
			Statistics		Δ_{min} = 0 bps		Δ_{min} = 5 bps		Δ_{min} = 10 bps		Statistics		Δ_{min} = 0 bps		Δ_{min} = 5 bps		Δ_{min} = 10 bps	
i	t_i		n	R_{50}	P	χ^2	P	χ^2	P	χ^2	n	R_{50}	P	χ^2	P	χ^2	P	χ^2
-3	11:57	S	1552	11.6	38.1***	7.1**	36.9	13.2***	33.3	45.3***	1754	10.9	49.8***	12.8***	40.8***	127.0***	30.4	461.5***
		S_{Lrg}	776	22.1	41.4***		41.4***		41.4***		877	20.6	54.0***		54.0***		54.0***	
		S_{Sml}	776	6.7	34.8		32.5		25.3***		877	4.2	45.5***		27.6***		6.8***	
-2	11:58	S	1555	11.6	38.6***	9.3**	37.5***	15.6***	33.8	50.3***	1754	10.9	50.2***	11.5***	40.5***	138.6***	30.0	492.8***
		S_{Lrg}	777	22.1	42.3***		42.3***		42.3***		877	20.6	54.3***		54.3***		54.3***	
		S_{Sml}	778	6.7	34.8		32.6		25.3***		877	4.2	46.2***		26.7***		5.7***	
-1	11:59	S	1562	11.7	38.9***	6.2*	37.6***	13.0***	34.1	43.1***	1754	10.9	50.3***	15.3***	40.5***	152.7***	30.6	492.2***
		S_{Lrg}	781	22.1	42.0***		42.0***		42.0***		877	20.6	55.0***		55.0***		55.0***	
		S_{Sml}	781	6.8	35.9		33.2		26.2***		877	4.2	45.6***		26.0***		6.2***	
0	12:00	S	1553	11.7	40.3***	6.3*	39.2***	11.9***	34.8	51.2***	1754	10.9	51.4***	10.6**	41.4***	139.9***	31.0	483.6***
		S_{Lrg}	776	22.1	43.4***		43.4***		43.4***		877	20.6	55.3***		55.3***		55.3***	
		S_{Sml}	777	6.8	37.2		34.9		26.1***		877	4.2	47.5***		27.5***		6.7***	
1	12:01	S	1576	11.7	28.1***	62.4***	28.6***	68.1***	38.3***	243.4***	1625	11.5	60.6***	116.5***	55.6***	213.4***	47.6***	442.5***
		S_{Lrg}	788	22.1	19.2***		19.2***		19.2***		812	21.5	73.6***		73.6***		73.6***	
		S_{Sml}	788	6.8	37.1		37.9		57.4***		813	5.2	47.5***		37.6		21.5***	
2	12:02	S	1457	11.9	38.2***	0.8	38.6***	0.3	42.6***	6.1*	1440	12.2	73.1***	210.0***	65.5***	382.9***	54.4***	736.7***
		S_{Lrg}	727	22.3	39.3***		39.3***		39.3***		720	23.0	90.0***		90.0***		90.0***	
		S_{Sml}	730	6.8	37.1		37.9		45.8***		720	5.4	56.1***		41.0***		18.8***	
3	12:03	S	1145	13.9	46.5***	22.7***	46.7***	21.1***	48.3***	12.4***	1118	13.9	78.0***	176.5***	71.6***	286.3***	59.4***	569.9***
		S_{Lrg}	572	23.8	53.5***		53.5***		53.5***		559	26.2	94.5***		94.5***		94.5***	
		S_{Sml}	573	7.1	39.4		40.0***		43.1***		559	6.4	61.5***		48.8***		24.3***	
4	12:04	S	831	14.6	53.8***	44.2***	53.7***	45.1***	52.8***	51.8***	751	15.4	79.8***	114.5***	74.6***	172.5***	64.2***	318.9***
		S_{Lrg}	415	26.0	65.3***		65.3***		65.3***		375	31.0	95.5***		95.5***		95.5***	
		S_{Sml}	416	7.2	42.3***		42.1***		40.4		376	7.6	64.1***		53.7***		33.0	
5	12:05	S	549	16.2	57.6***	46.0***	57.7***	44.9***	56.3***	54.2***	512	16.9	82.0***	76.5***	76.0***	122.5***	66.6***	211.0***
		S_{Lrg}	274	29.5	71.9***		71.9***		71.9***		256	33.1	96.9***		96.9***		96.9***	
		S_{Sml}	275	7.7	43.3***		43.6***		40.7		256	7.8	67.2***		55.1***		36.3	
6	12:06	S	380	17.1	62.6***	43.2***	62.9***	42.0***	61.8***	47.1***	335	17.5	80.3***	46.8***	74.9***	72.9***	67.5***	116.8***
		S_{Lrg}	190	32.2	78.9***		78.9***		78.9***		167	33.6	95.2***		95.2***		95.2***	
		S_{Sml}	190	9.4	46.3***		46.8***		44.7***		168	7.7	65.5***		54.8***		39.9	
7	12:07	S	263	19.1	65.4***	27.8***	64.6***	30.3***	62.7***	36.9***	225	19.0	83.6***	26.9***	77.8***	44.9***	70.2***	73.2***
		S_{Lrg}	131	33.7	80.9***		80.9***		80.9***		112	41.9	96.4		96.4		96.4	
		S_{Sml}	132	9.8	50.0***		48.5***		44.7		113	8.1	70.8***		59.3***		44.2	

At each interval i a sub-sample of the fixings yet to have completed is selected (**S**).This sub-sample is further divided into S_{Lrg} and S_{Sml}, with S_{Lrg} containing fixings with absolute fix returns larger than the median absolute fix return of **S** and the remained placed in S_{sml}. The horizontal line demarks intervals before the fixing start ($i<1$) from those after the fixing start ($i≥1$). For each sub-sample, n reports the sample size and R_{50} reports the median absolute fix return in basis points (bps). The proportion of fixings where the sign of the fix return is correctly predicted by the market return is reported by **P**, with the proportion z-test of **P** = $^1/_3$ significance denoted by *, **, *** for at 5%, 1% and 0.1% respectively. A return is classified as *positive* when it exceeds Δ_{min}, *negative* when below -Δ_{min}, and flat when between -Δ_{min} and Δ_{min}. χ^2 reports the Chi-squared test statistics for $Pr(S_{Lrg}) = Pr(S_{Sml})$ with *,**,*** denoting significance at 5%,1% and 0.1% respectively. The sample period covers January 1, 2000 to December 31, 2013, split between Panel A and Panel B containing 1,624 and 1,754 fixing samples respectively.

Panel A –Start of fixing aligned analysis window

Panel B –End of fixing aligned analysis window

Figure 1 – Analysis window definitions

The top illustration (panel A) shows an analysis window aligned to the start of the fixing. All intervals are referenced to 12:00 Noon (London), with the last one minute interval before the start of the fix denoted as $i=0$. The fixing period varies day to day, and does not correspond to a fix time of day. A 15 minute reference period, offset 15 minutes prior the fixing, is defined for use in the volume and volatility analysis. The next illustration (Panel B) shows the same elements, but in this case aligned to the end of the fixing. In this case, $i=0$ corresponds to the last one minute interval before the fix ends. This does not correspond to a fixed time of the day. The reference period in this case is placed 15 minutes after the fixing end, lasting the same 15 minutes.

SI 5 Minute Cumulative Unadjusted Returns (2007-2013)
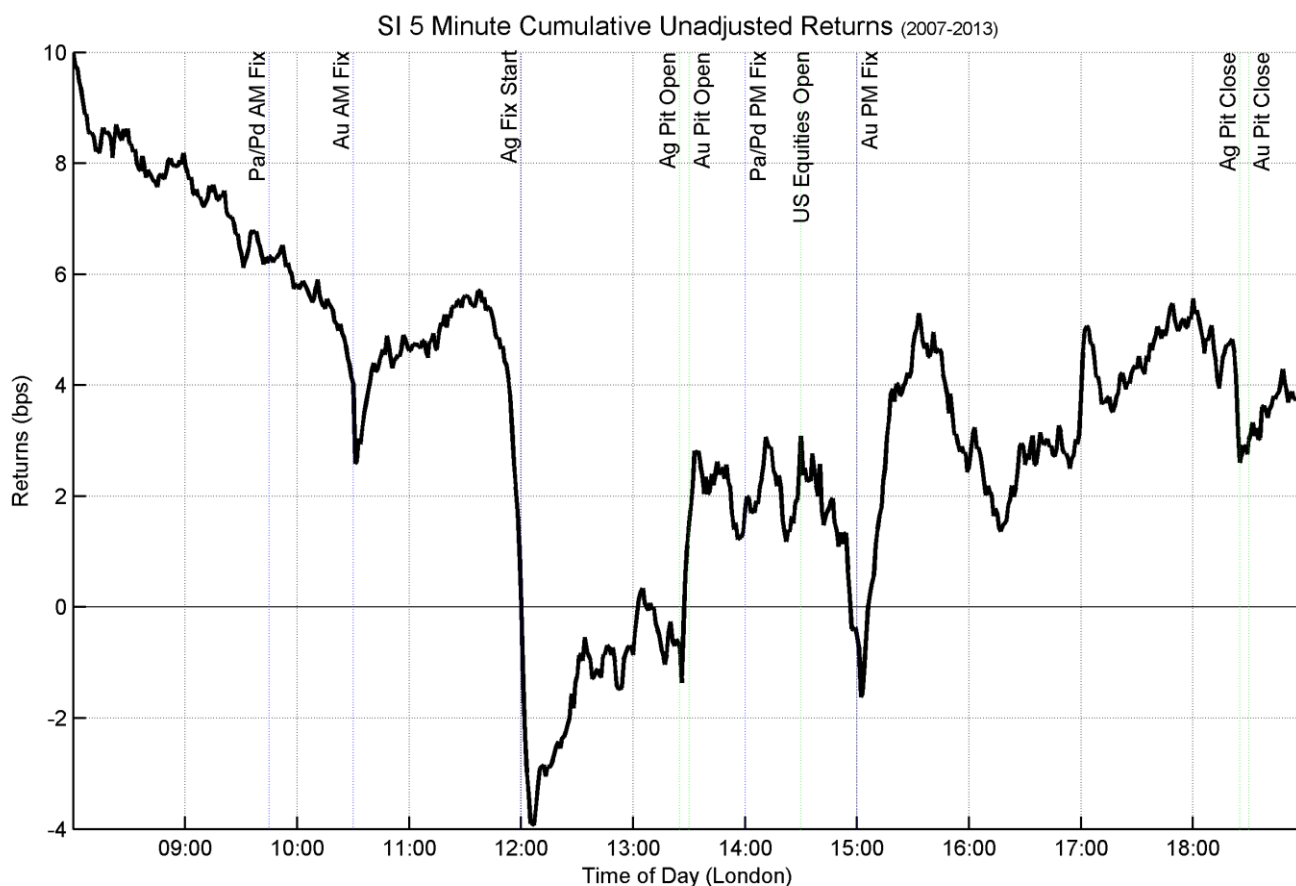
Figure 2 - Cumulative Returns on Silver Futures (SI) during London trade day

Silver futures (SI) cumulative returns throughout the London trading day, reference to the start of the silver fixing. The chart shows the price of silver falling approximate 10bps around the time of the London silver fixing, which occurs at noon each day. Key intraday events are annotated with vertical lines, Ag, Au, Pa, Pd referring to silver, gold, platinum and palladium respectively. The samples covers all fixings from 1st January 2007 through to 31st December 2013, and includes 1754 trade days. Results for spot silver (XAG), not shown here, are largely similar.
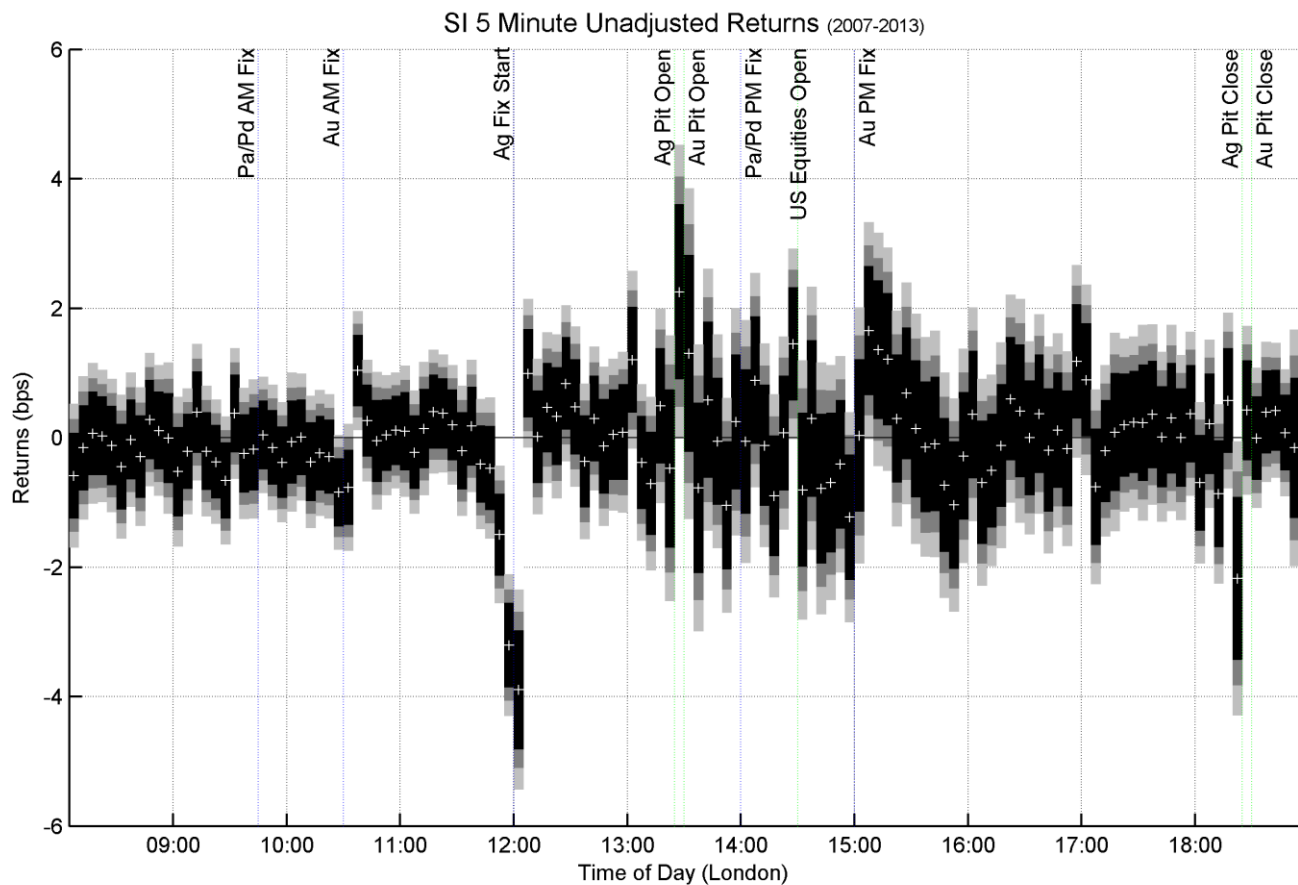
Figure 3 - Returns on Silver Futures (SI) during London trade day

Silver futures (SI) 5 minute returns. The chart shows mean 5 minute log returns throughout the London trade day. The "+" markers signify the mean returns whereas the 95%, 99% and 99.9% confidence intervals are depicted by the black, dark grey and light gray bars surrounding the mean. Statistically significant returns are noted around the time of the London silver fixing, which occurs at noon each day. Key intraday events are annotated with vertical lines, Ag, Au, Pa, Pd referring to silver, gold, platinum and palladium respectively. The samples covers all fixings from 1st January 2007 through to 31st December 2013, and includes 1754 trade days. Results for spot silver (XAG), not shown here, are largely similar.
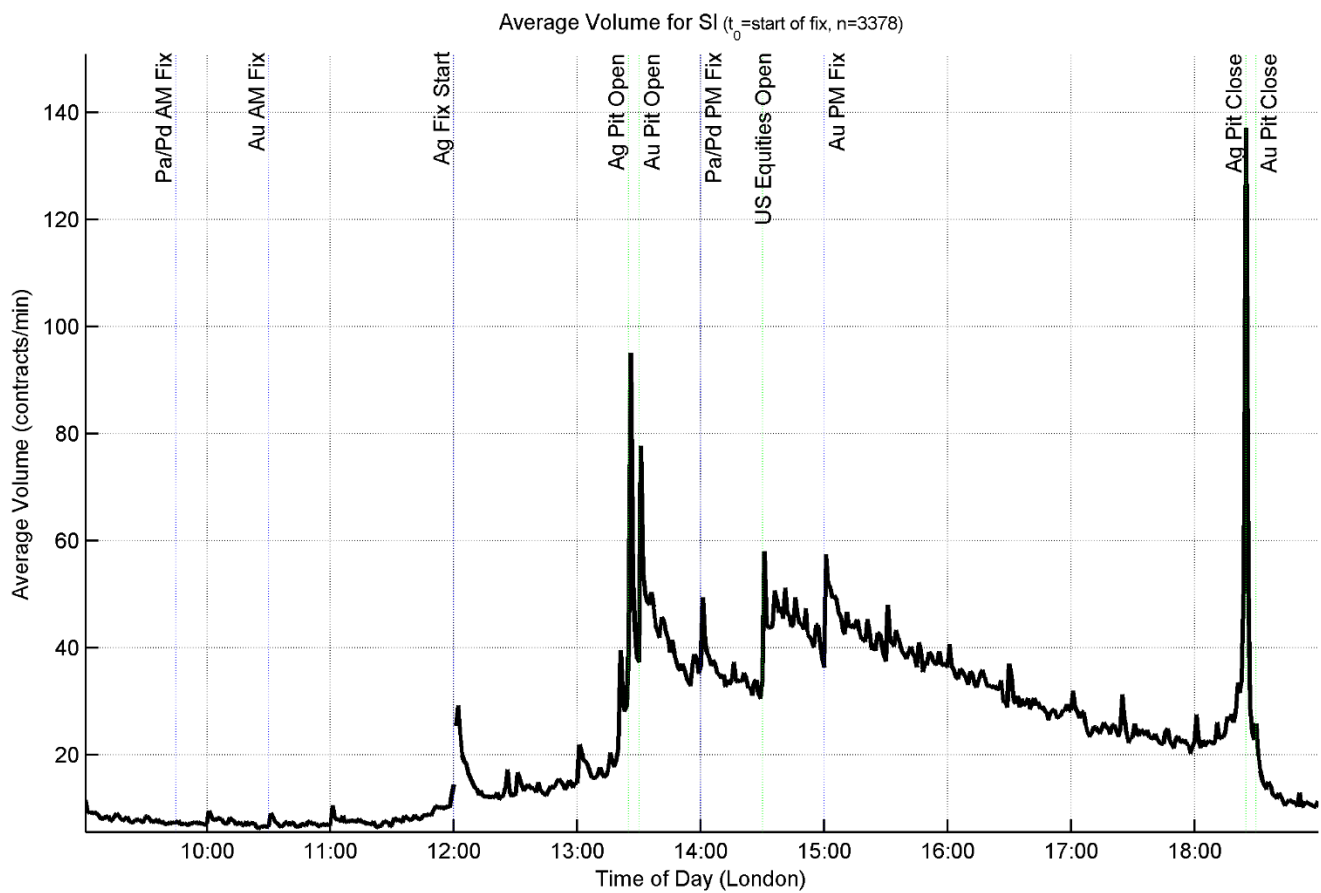
Figure 4 – Trade Volume of Silver Futures (SI) during London trade day

Silver futures (SI) trade volume in contracts per one minute interval throughout the London trade day. The London silver fixing occurs at noon each day, and other key intraday events are annotated with vertical lines, Ag, Au, Pa, Pd referring to silver, gold, platinum and palladium respectively. The samples covers 3,378 fixings trade days from 1st January 2000 through to 31st December 2013.
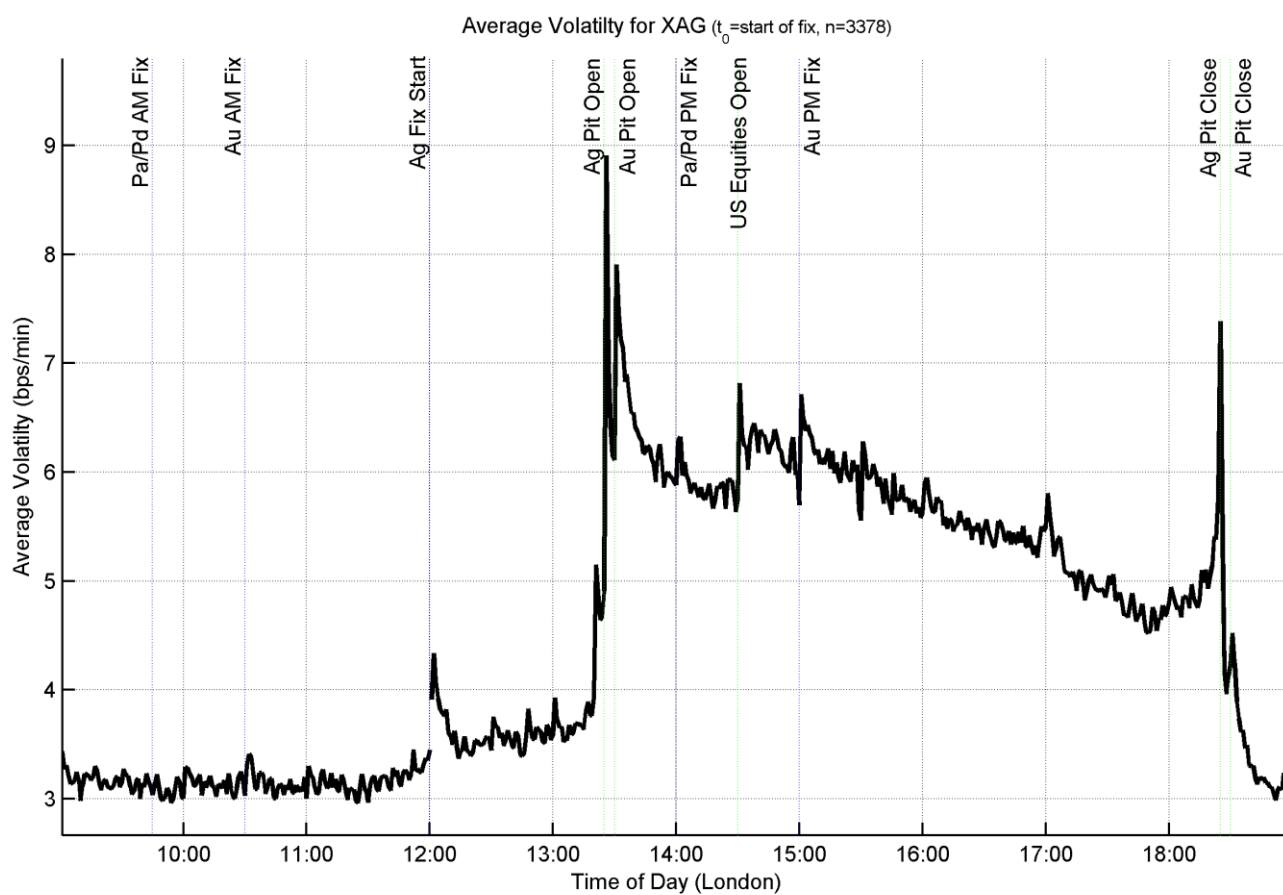
Figure 5 – Price Volatility of Spot Silver (XAG) during London trade day

Spot silver (XAG) price volatility in basis points (bps) per minute throughout the London trade day. The London silver fixing occurs at noon each day, and other key intraday events are annotated with vertical lines, Ag, Au, Pa, Pd referring to silver, gold, platinum and palladium respectively. The samples covers 3,378 fixing trade days from 1st January 2000 through to 31st December 2013.
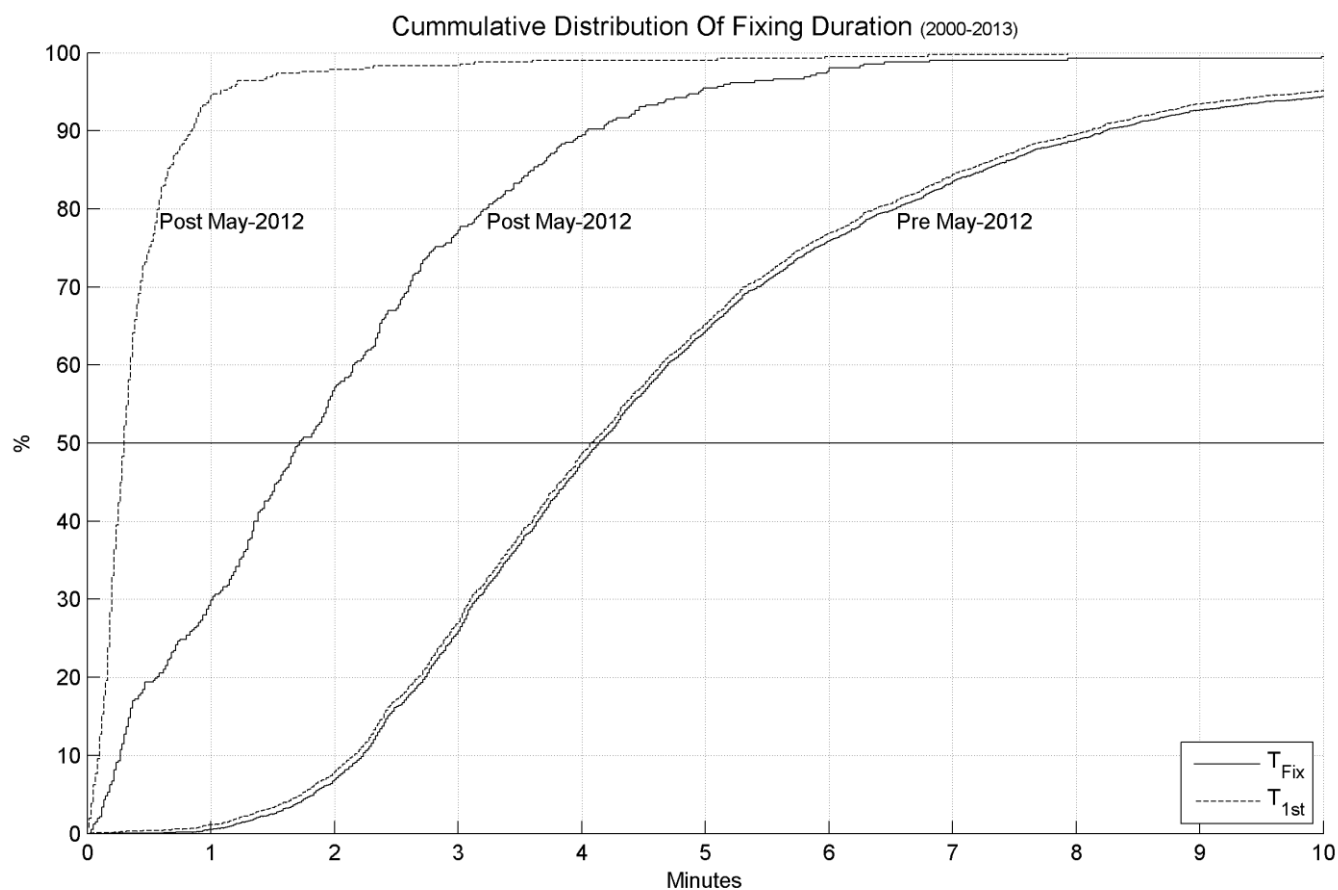
Figure 6 – Distribution of Silver Fixing durations (2000-2013)

Shown are the cumulative distributions functions (CDFs) of fixing periods (T_{Fix}) and first market update periods (T_{1st}). Distributions pre and post May 2012 are shown to highlight the change in the silver fixing. Prior to May 2012, there is little difference between T_{Fix} and T_{1st}. The sample covers 3,378 fixings from 1st January 2000 through to 31st December 2013, with 2,960 fixings occurring before 1 May 2012 and 418 after.
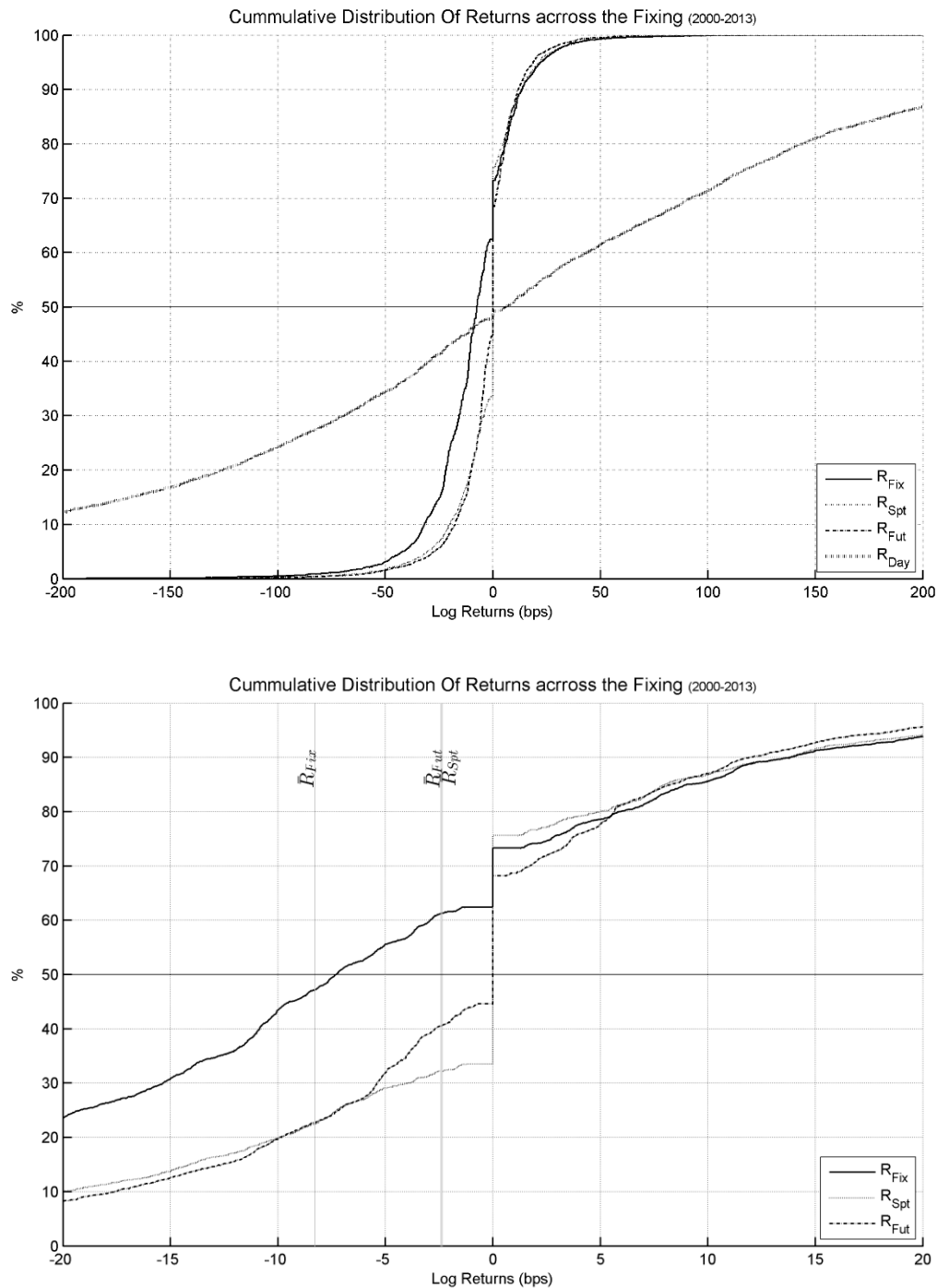
Figure 7 – Distribution of Silver Fixing returns (2000-2013)

Empirical cumulative distribution function of returns across the daily London silver fixing. R_{Fix} , R_{Spt} and R_{Fut}, refer to Fix, Spot and Futures returns. All returns are log returns calculated from quote mid-points immediately before and after the fixing period. Fix returns use the spot price as the initial price and the final fixing result as the terminal price. R_{Day} is the return from the previous fixing to the current fixing. Top chart provides an overall view of the four distribution and covers returns to +/- 200 bps. The intraday returns are noticeably less disperse than the daily returns. The bottom chart zooms in to +/- 20 bps, to better illustrate the differences between the three intraday results. For each return the median of each can be seen at the 50% intercept, and sample means are annotated with the labeled verticals. The sample covers 3,378 fixings from 1 January 2000 through to 31 December 2013.
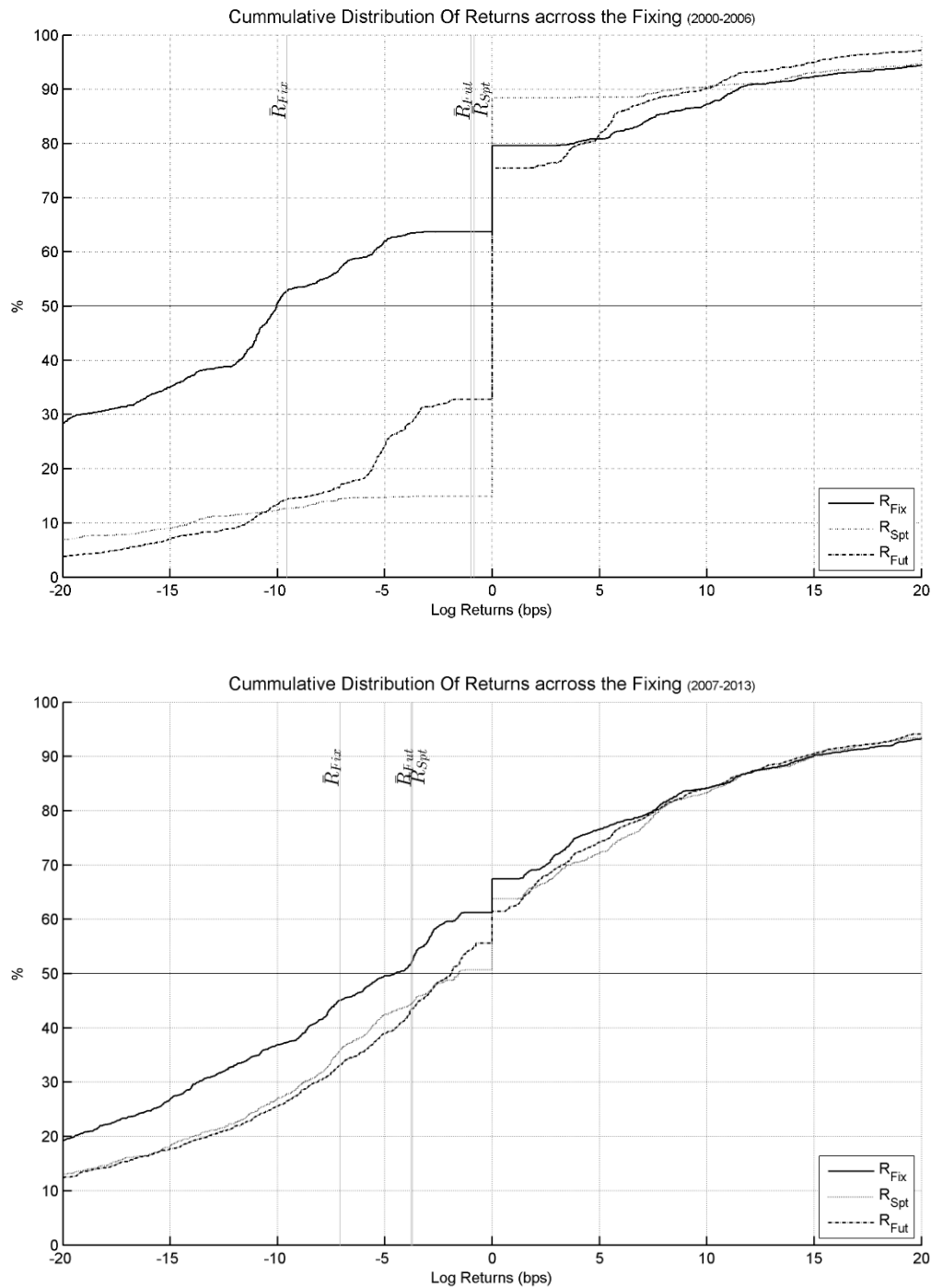
Figure 8 – Distribution of Silver Fixing returns pre and post 2007

Empirical cumulative distribution functions (ECDFs) of returns across the daily London silver fixing. R_{Fix}, R_{Spt} and R_{Fut}, refer to Fix, Spot and Futures returns. All returns are log returns calculated from quote mid-points immediately before and after the fixing period. Fix returns use the spot price as the initial price and the final fixing result as the terminal price. For each of the three returns, the sample median is shown at the 50% horizontal intercept, while the sample mean is annotated with the labeled verticals. The top chart shows the ECDFs from 1 January 2000 to 31 December 2006, covering 1,624 fixings, whereas the bottom chart ranges from 1 January 2007 to 31 December 2013, covering 1,754 fixings.

KS Comparison of Spot vs Futures returns (2000-2013)

KS Comparison of Spot vs Fixing returns (2000-2013)
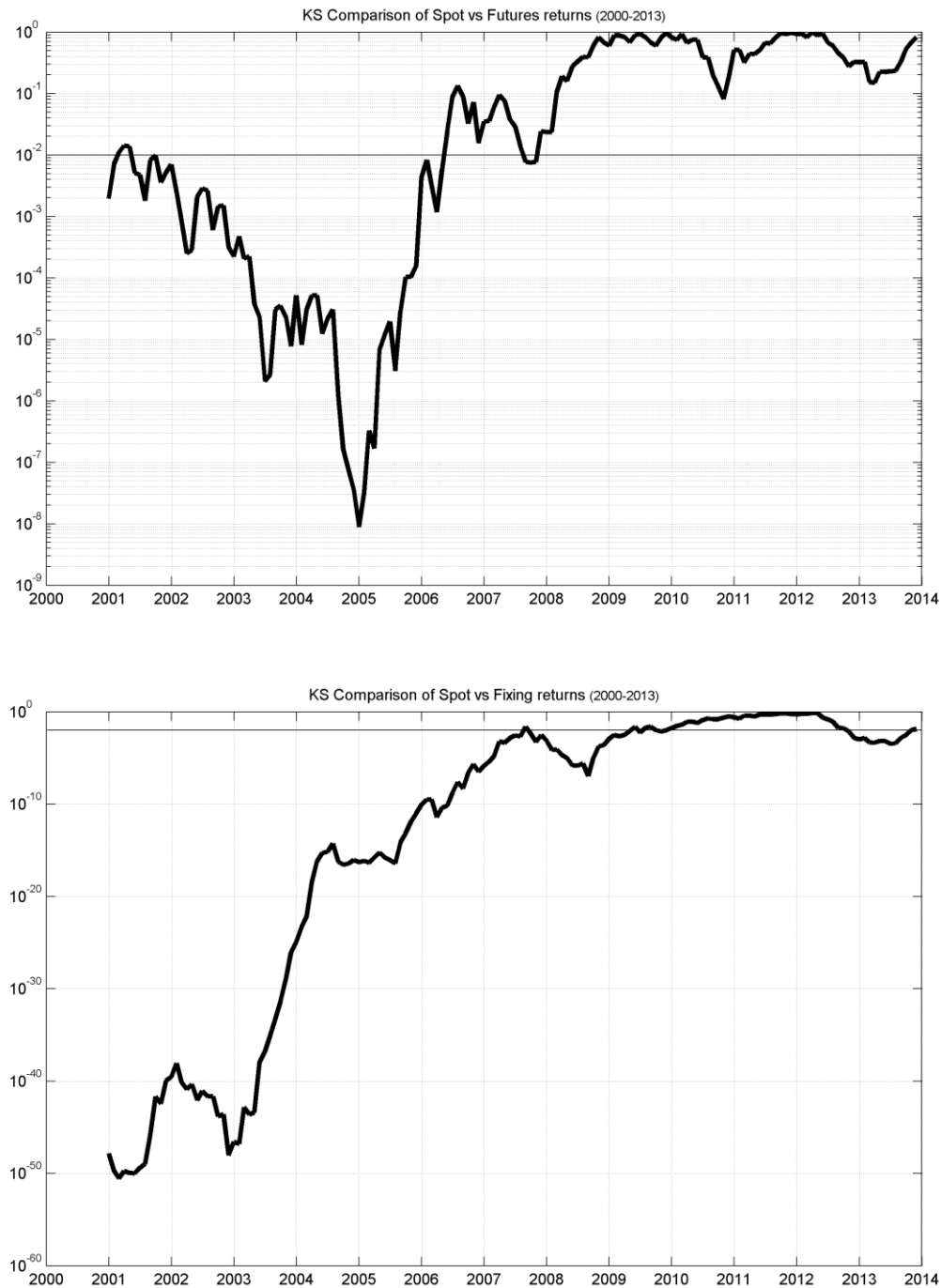
Figure 9 – Comparisons of Silver Fixing return distributions

These graphs show the results of the Kolmogorov-Smirnov test, used to compare two empirical distributions. The top chart compares silver spot (R_{spt}) and futures returns (R_{fut}) across the fixing, while the bottom chart compares spot and fix returns (R_{Fix}). Results below the horizontal at 10^{-2} indicate rejection of the hypothesis that the two samples are drawn from the same underlying distribution, to 1% significance. A one year sliding window is used, with results reported at the end date of the widow. Returns converge after 2007. The sample covers 3,378 fixings from 1 January 2000 through to 31 December 2013 for which spot and futures markets were open.
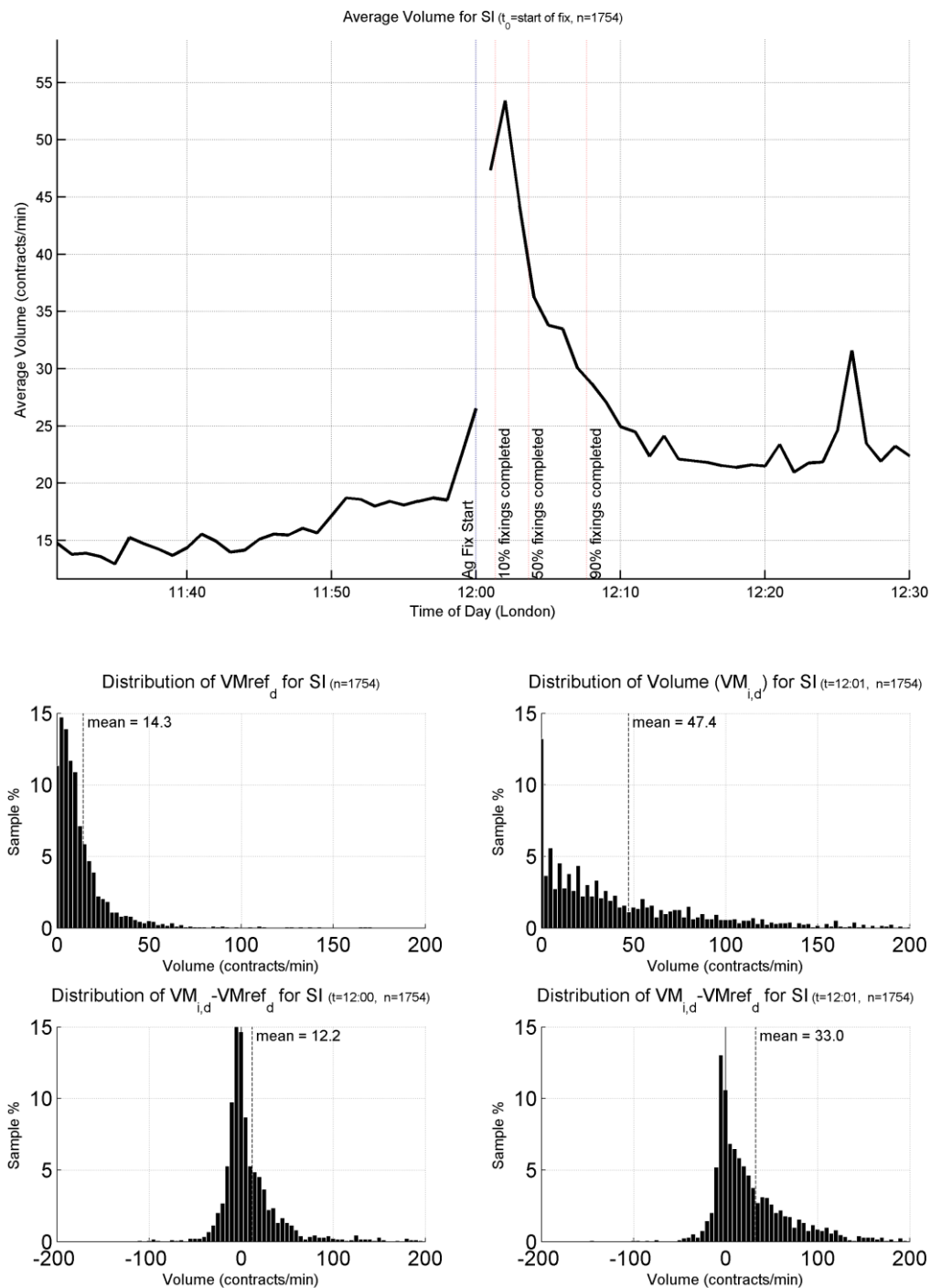
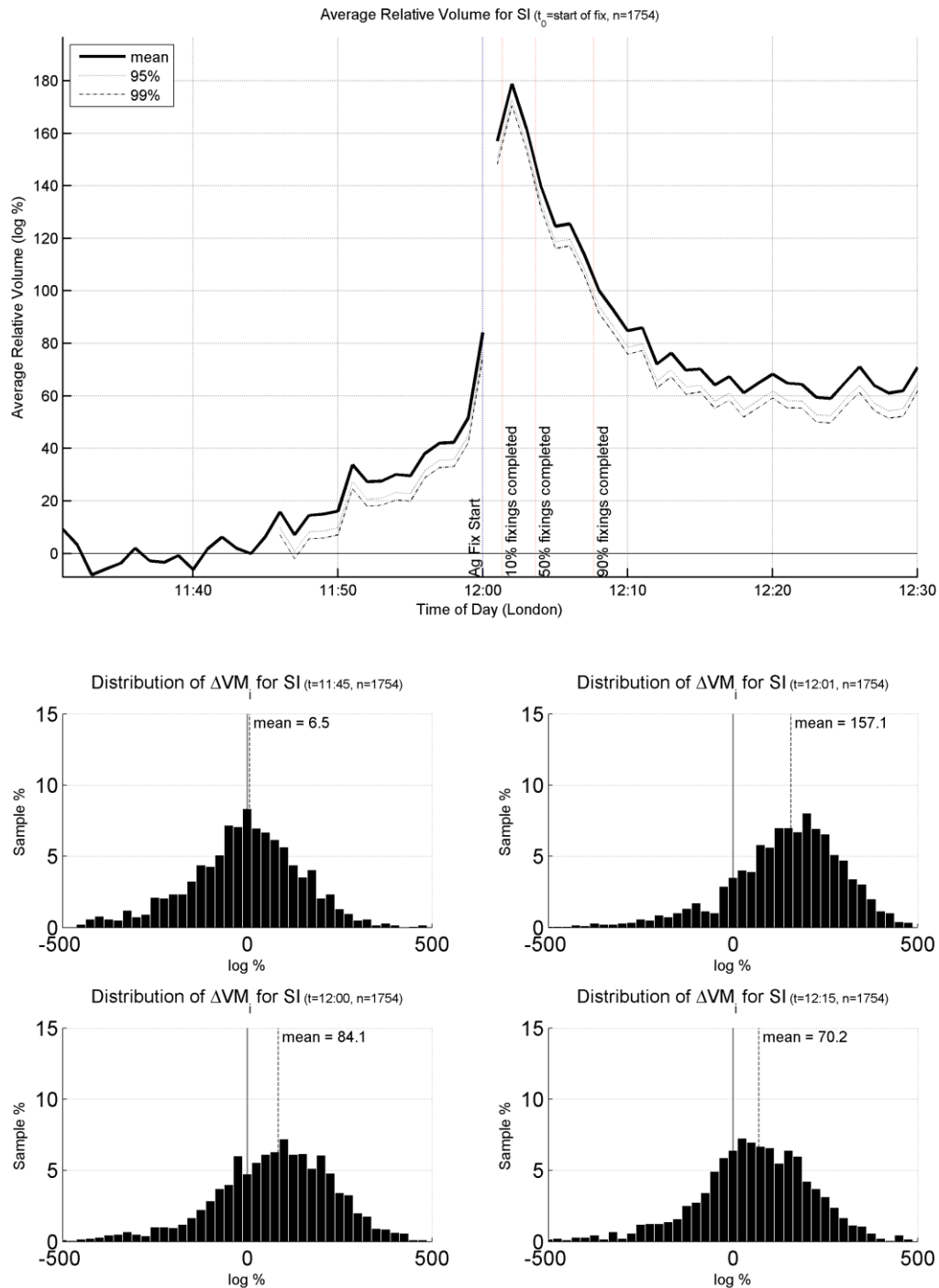**Figure 10 – Change in trade volume of Silver Futures (SI) at the time of the fixing**

These graphs shows the impact the start of the silver fixing has on futures trade volume. The trade volume is compared to a reference level derived from averaging the trade volumes from 11:30AM through 11:45AM (London). The fixing start and time at which 10%, 50% and 90% of the fixing have finished are marked with annotated verticals. A peak in trade volume occurs two minutes in to the fixing, well before the majority of fixings have concluded. The samples covers 1,754 fixings from 1st January 2007 through to 31st December 2013.

Figure 11 – Change in relative trade volume of Silver Futures (SI) at the time of the fixing

These graphs shows the impact the start of the silver fixing has on futures trade volume. The trade volume is compared to a reference level derived from averaging the trade volumes from 11:30AM through 11:45AM (London). The fixing start and time at which 10%, 50% and 90% of the fixing have finished are marked with annotated verticals. A peak in trade volume occurs two minutes in to the fixing, well before the majority of fixings have concluded. The samples covers 1,754 fixings from 1st January 2007 through to 31st December 2013.
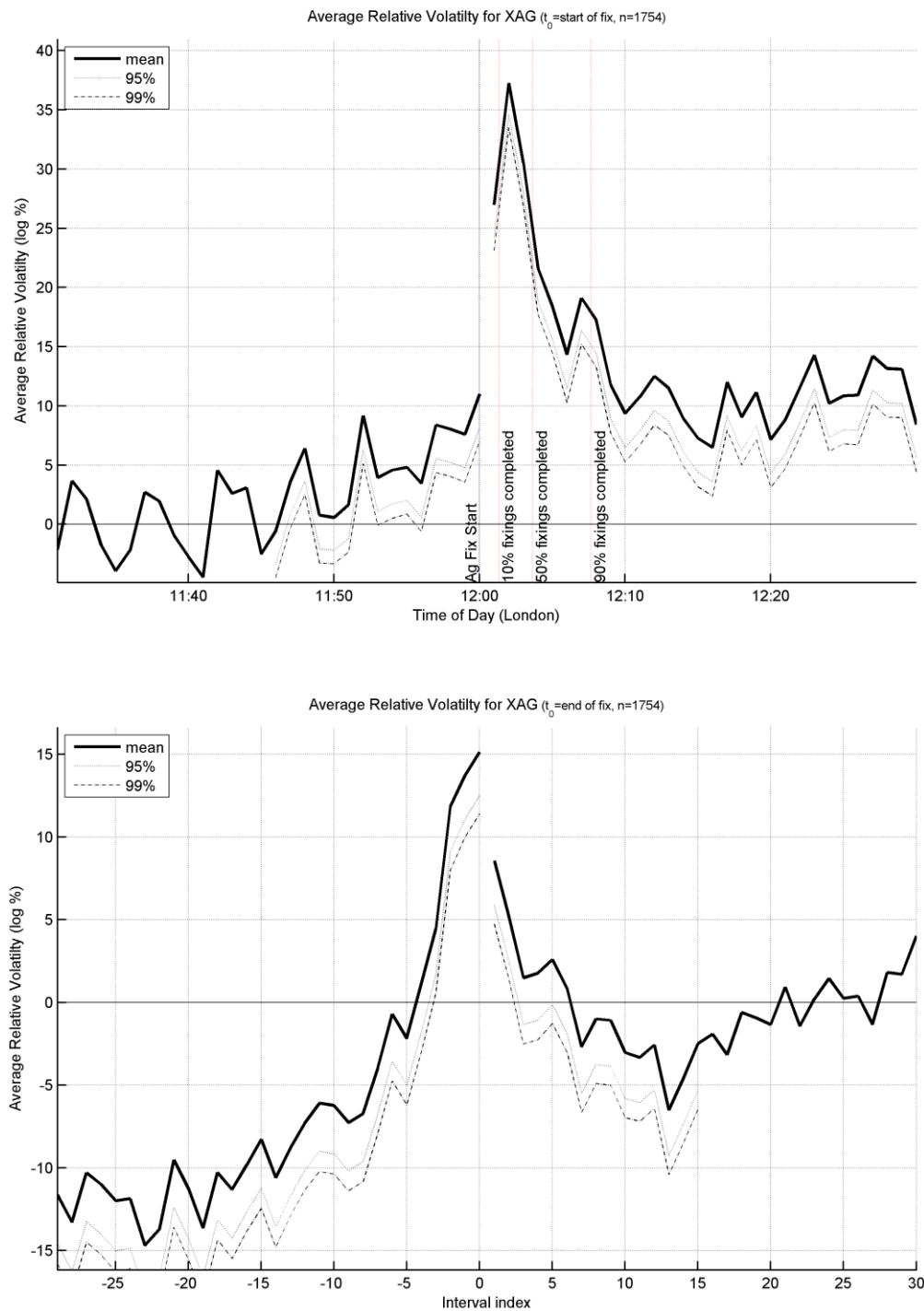
Figure 12 – Change in Spot Silver (XAG) price volatility at the time of the fixing

These graphs shows the impact the start of the silver fixing has on spot silver price volatility. The top chart shows the price volatility reference to the start of the fixing, which starts at Noon (London) each day. The bottom chart references to the end of the fixing. The price volatility is compared to a reference level, defined to be the average price volatility from 30 to 15 minutes pre (post) the fixing start (end), in the case of the top (bottom) chart. Elevated price volatility is shown starting five minutes prior the start of the fixing, reaching a peak two minutes into the fixing. Peak volatility occurs prior the publication of the fixing result. The samples covers 1,754 fixings from 1st January 2007 through to 31st December 2013. Results for silver futures (SI), not shown here, are largely similar.
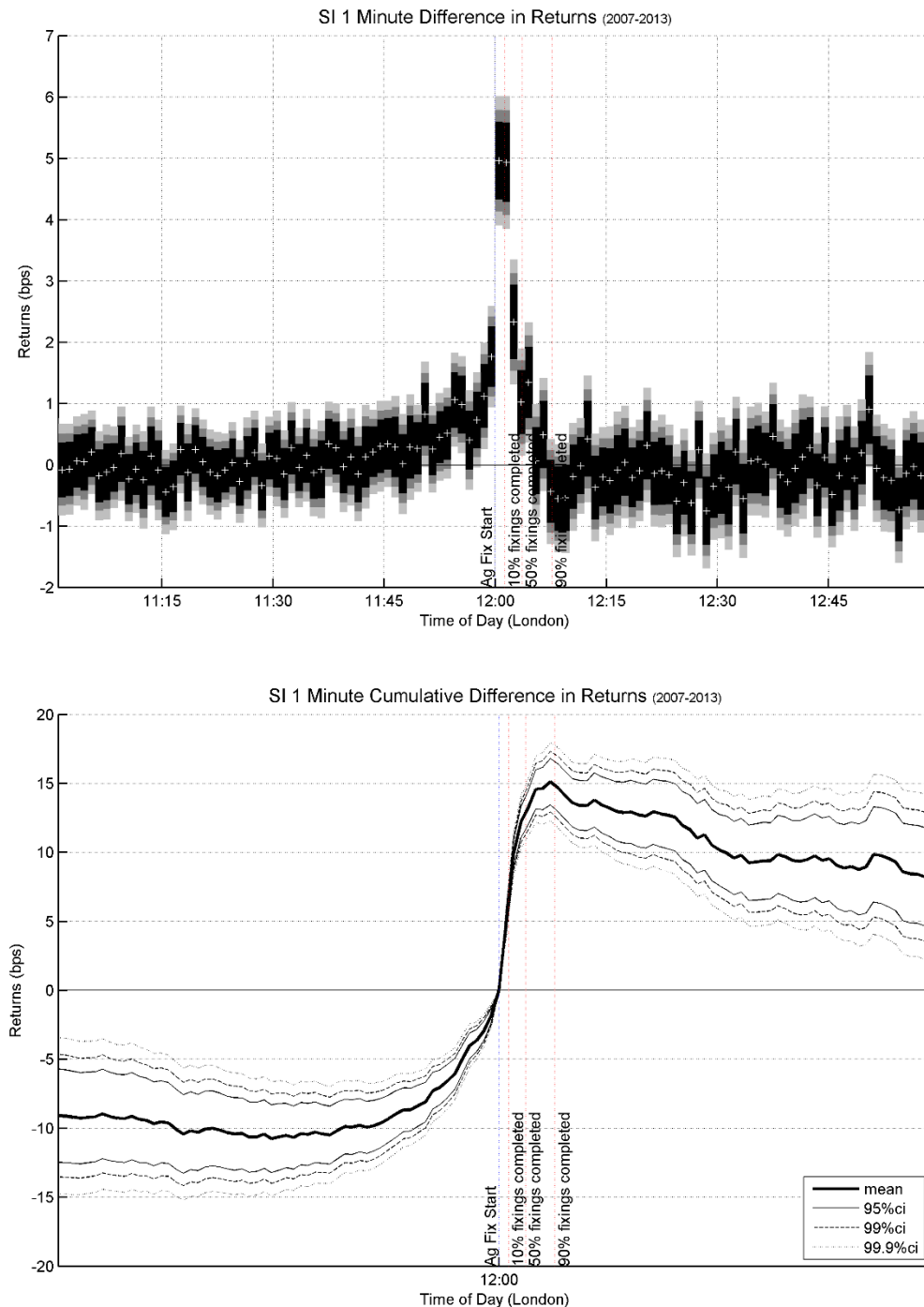
Figure 13 – Silver Futures (SI) Difference in Returns (DR) and Cumulative DR (CDR) at the time of the fixing

The top chart shows the largest difference in returns (DR) are observed in the opening five minutes of the fixing, with some significant DRs also being present in the ten minutes prior to the start of the fixing. The DR is defined as the difference between the adjusted returns and unadjusted returns, where adjusted returns are "adjusted" for the price direction of the fixing, and show the advantage an informed trader has over an uninformed long position. The "+" markers signify the mean returns whereas the 95%, 99% and 99.9% confidence intervals are depicted by the black, dark grey and light gray bars surrounding the mean. The cumulative DR (CDR) is zeroed at the start of the fixing, and is shown in the bottom chart. The CDR chart illustrates both the timing and magnitude an informed trader has over the uninformed trader. Up to 25bps is available to the informed trader, depending on when they become informed. 95%, 99% and 99.96% two-tailed confidence intervals are provided to illustrate statistical significance. Results for spot silver (XAG), not shown here, are largely similar. The samples 1754 fixings from 1st January 2007 through to 31st December 2013.
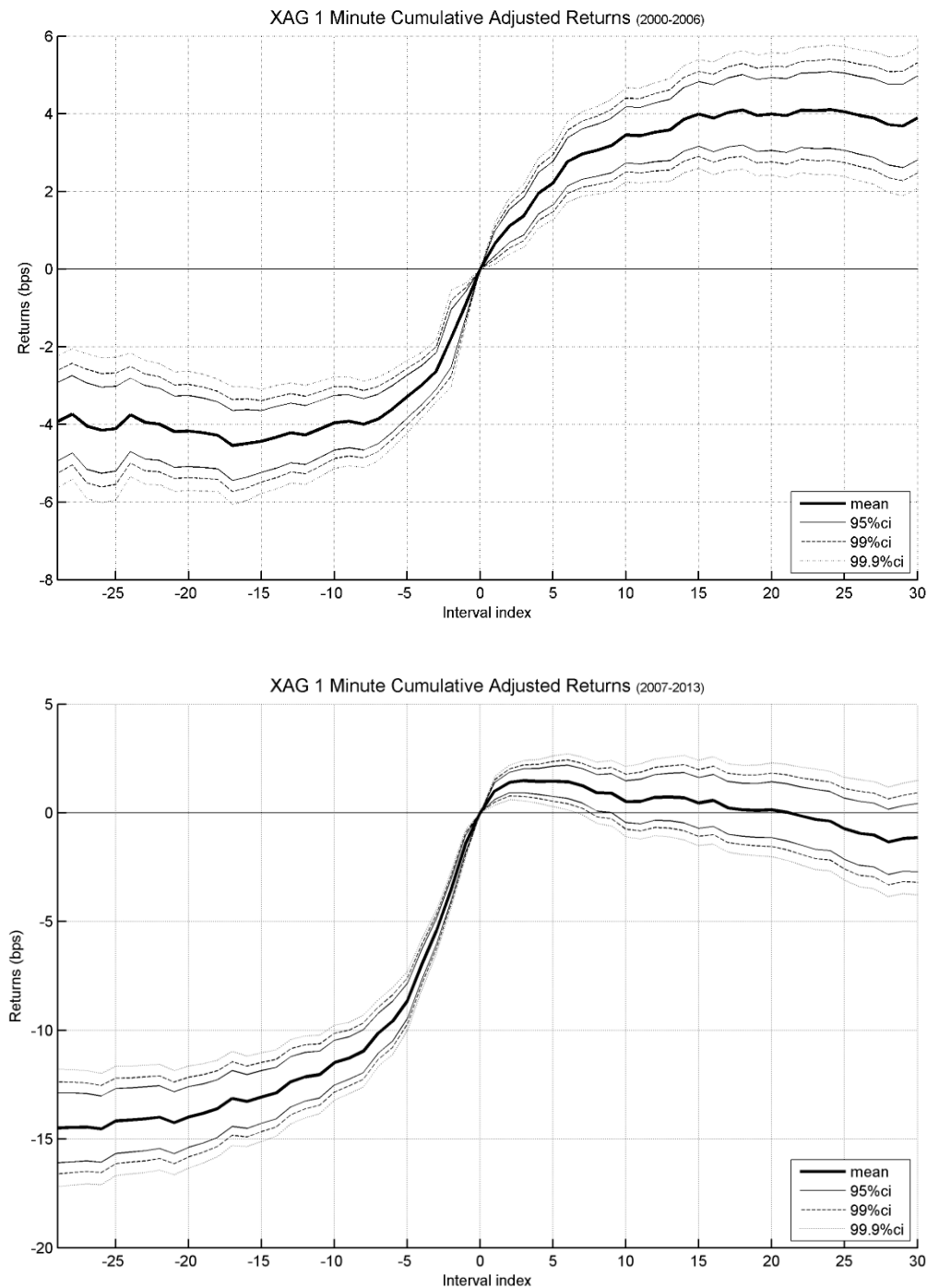
Figure 14 – Spot Silver (SI) Cumulative Adjusted Returns (CDR) at the end of the fixing

Adjusted returns are "adjusted" for the price direction of the fixing and show the returns available to a directional informed trader is zeroed at the end of the fixing and illustrates the value of the direction information relative to the end of the fixing. Pre 2007, approximately 8bps is available spread evenly before and after the fixing. Post 2007, approximately 15 bps is available be virtually all before the end of the fixing, ie. there is no value in the knowing the fixing direction after it is published. 95%, 99% and 99.96% two-tailed confidence intervals are provided to illustrate statistical significance. Results for silver futures (SI), not shown here, are largely similar. The samples 1754 fixings from 1st January 2007 through to 31st December 2013.
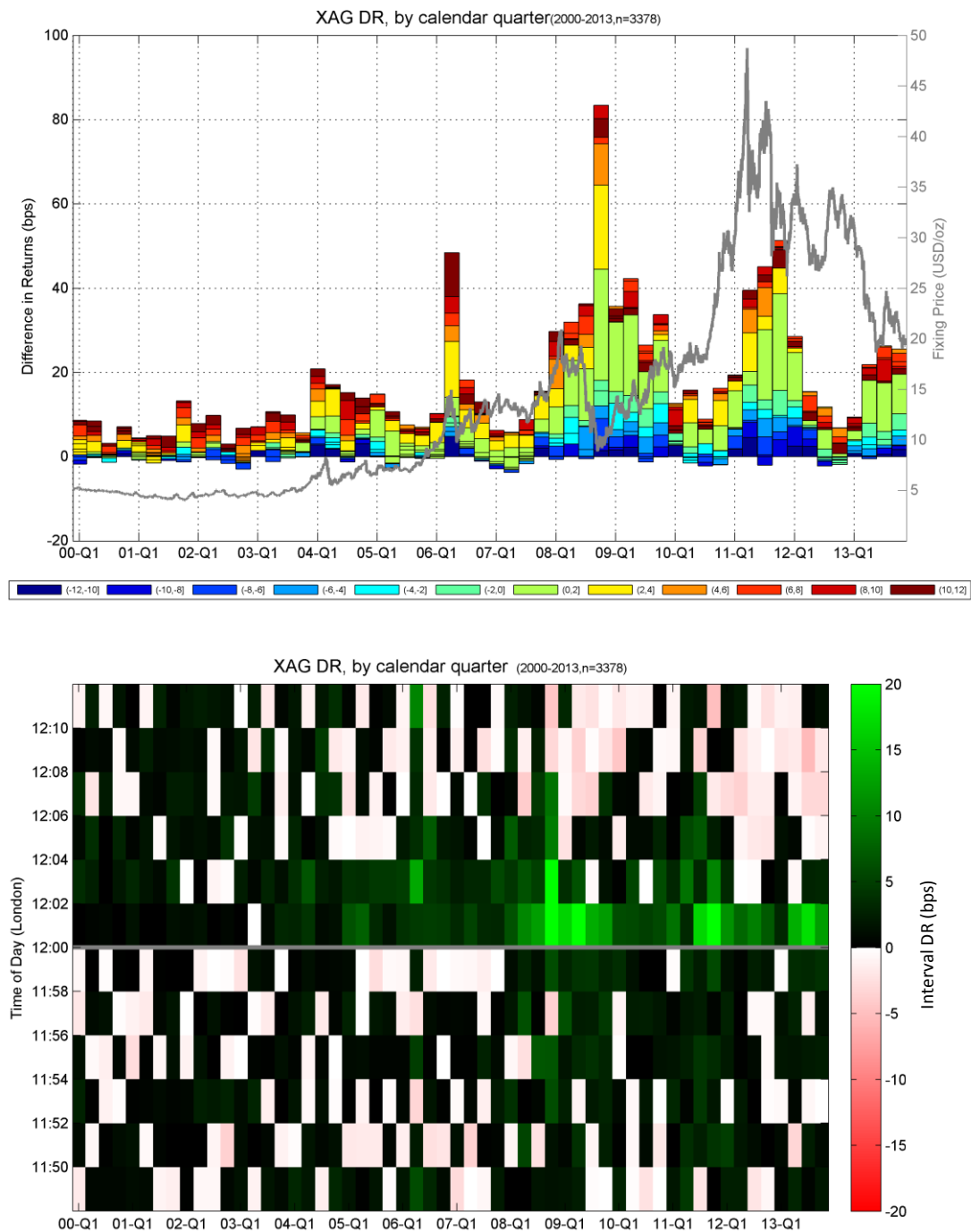
Figure 15 – Spot Silver (XAG) Cumulative Difference in Returns (CDR) over time

The difference in returns (DR) is defined as the difference between the adjusted returns and unadjusted returns, where adjusted returns are "adjusted" for the price direction of the fixing. DR shows the advantage an informed trader has over an uninformed trader. The top chart shows the average DRs (left axis) per calendar quarter and across two minute intervals reference to the start of the fixing. Overlaid is the silver price (right axis) for the same period. Its shows DRs have varied over time, and not directly related to the silver price. DRs have, however, remained positive for the whole sample period with the first two minutes of the fixing yielding the largest DRs. The bottom chart shows a heat map of the DRs, illustrating that the opening two minutes have positive returns each quarter, in some cases exceeding 20bps. Results for silver futures (SI), not shown here, are largely similar. The samples covers 3,378 fixings from 1st January 2000 through to 31st December 2013.
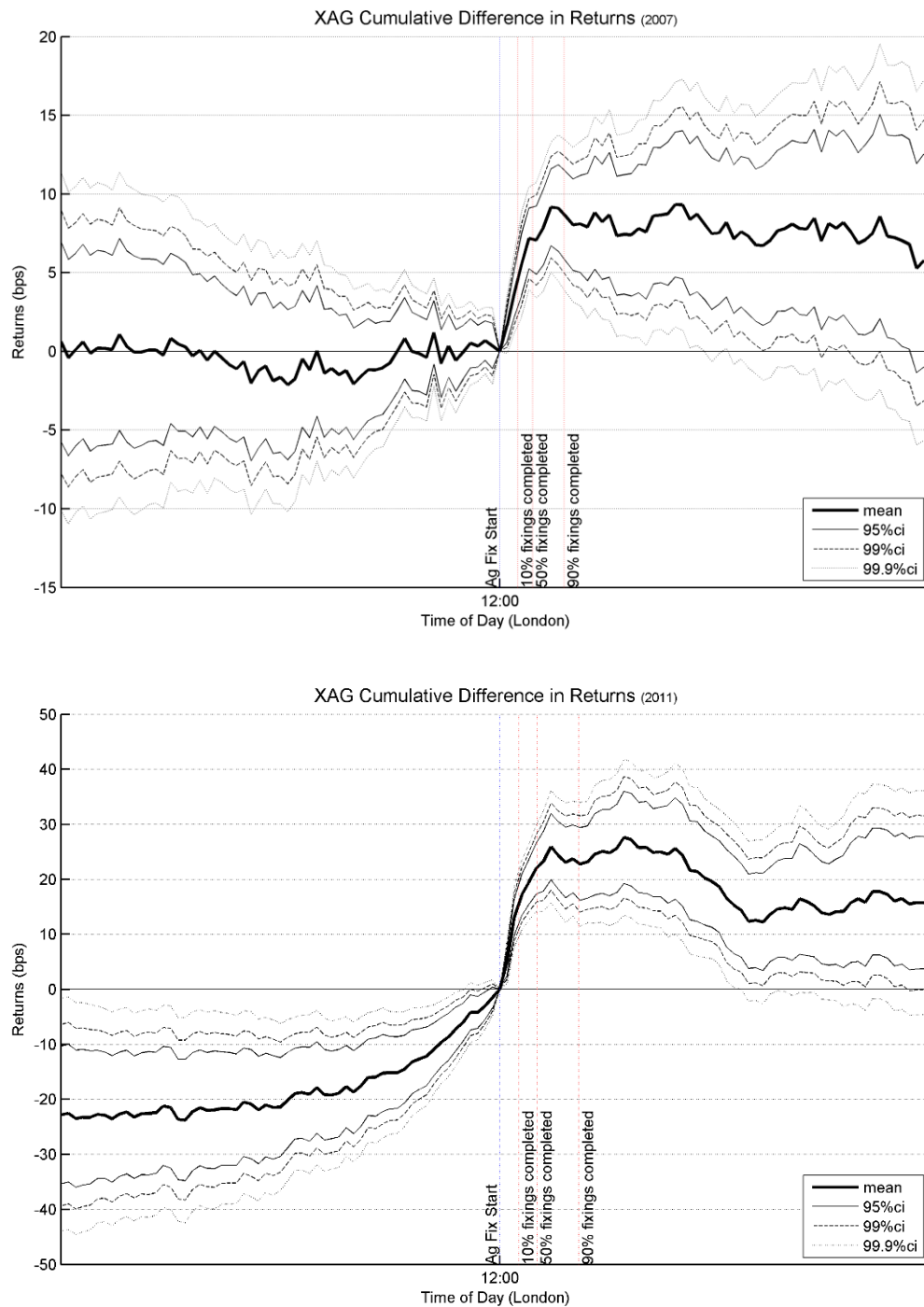
Figure 16 –Cumulative Difference in Returns (CDR) for Spot Silver (XAG): 2007 vs 2011

These charts show the mean cumulative difference in returns across two years, 2007 in the top chart and 2011 in the bottom chart. The difference in returns is defined as the difference between the adjusted returns and unadjusted returns and shows the advantage an informed traded has over an uninformed long position. In 2011 this information advantage is shown to be approx. 40 bps and starts to accumulate around 10 minutes before the fixing. This contrasts with 2007 where there is no significant advantage prior the fixing start and the advantage averages around 10bps. Results for silver futures (SI), not shown here, are largely similar.
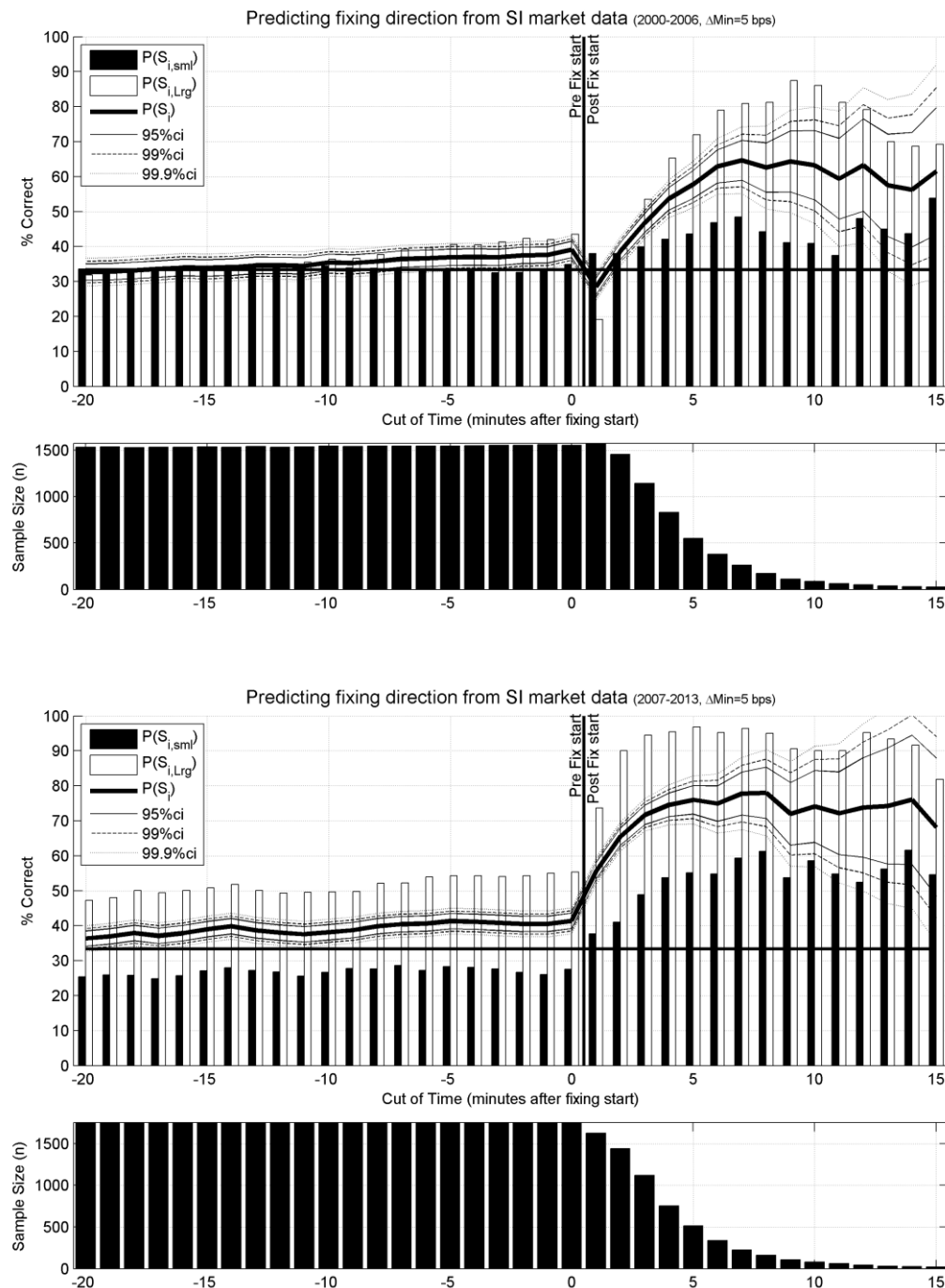
Figure 17 – Predicting Fixing Direction from Silver Futures (SI) market data

These graphs show the predictability of the fixing direction as a function of minutes from the start of the fixing. The percentage of correct predictions (**P**) is given on the vertical axis. The direction of the fixing (positive, negative or flat) is made on the basis of the returns observed in the market up to close of interval **i**. The full sample (**S**) only includes fixings still in process at the close of interval **I**, i.e. completed fixings are removed from **S**. This sub-sample is further divided into S_{Sml} and S_{Lrg}, based on the magnitude of absolute fix returns. Before the start of the fixing (**i<1**), market returns show rates similar to $1/_3$, the level expect from random guessing. Returns in the opening two to four minutes, however, show high levels of prediction. Post 2007, the levels of prediction are both higher, occur earlier, and show a higher differentiation between 'large' and 'small' fixings. Results for spot silver (XAG), not shown here, are largely similar. The samples covers 3,378 fixings from 1 January 2000 through to 31 December 2013.