An Empirical Analysis of Market Microstructure in Gold and Platinum Futures

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(Degree)
博士 (経済学)
(Date of Degree)
2018-03-25
(Date of Publication)
2020-03-25
(Resource Type)
doctoral thesis
(Report Number)
甲第7097号
(URL)
https://hdl.handle.net/20.500.14094/D1007097

博　士　論　文

平成 29 年 12 月

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An Empirical Analysis of Market Microstructure in Gold and Platinum Futures

（金とプラチナ先物市場のマイクロストラクチャーに関する実証分析）

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Chapter 1. Introduction

For decades, a surge of investors have considered commodities as a potential investment tool, especially precious metals. Precious metals (such as gold, silver, platinum and palladium) which have served as monetary and international exchange are attracting much attention for many reasons. They are different from other agricultural commodities (such as corn and wheat), because of their durability, storability and being standardized. Price volatility of precious metals is reacting to the interactions of global factors such as inflation, interest rates and various economic and political events. And of all the precious metals, gold and platinum are the most popular as the investment. Investors generally buy gold and platinum as portfolio diversification, inflation and currency hedge and risk management, because gold and platinum are not only low correlate to many equity markets and less volatile than most commodities, but also can diversify risk and retain long term purchasing power.

Gold and platinum are traded OTC (over-the-counter) worldwide and financial precious metals products, such as ETFs (exchange-traded funds), futures and other derivatives on a wide variety of organized exchanges and platforms. Arbitrageurs and speculators pay close attention to the pricing relationship of gold and platinum across markets around the globe. Gold and platinum have standard quality and storage characteristics that enable arbitrage in cross-market futures trading. It seems apparent that the pricing of gold and platinum reflects global forces rather than local factors. Therefore, we ask how information of gold and platinum are transmitted across markets throughout the world. Gold and platinum futures are hedging tools for commercial products and users of them. They also provide global gold and platinum price discovery and opportunities for portfolio diversification.

Many of gold and platinum futures exchanges and platforms have extended their trading hours to include night sessions, overlapping with each other. It is now common for different exchanges to trade futures based on the same underlying commodity at the same time. Arbitrage activity, assisted by the globalization of commodity markets and advances in trading technology, encourages commodity futures mid-prices on different exchanges to be virtually identical after adjusting for contract specifications and exchange rates. A straightforward argument would suggest that market participants prefer to trade on the exchange with superior price discovery, efficiency and liquidity. Therefore, trade in the futures of a particular commodity would be expected to agglomerate to one exchange, as higher liquidity and scale economies encourage traders to the venue. However, multiple futures exchanges persist for many commodities.

There are three main worldwide organized exchanges and platforms of gold and platinum, UK (LBMA), Japan (TOCOM) and U.S. (NYMEX). The LBMA (London Bullion Market Association) established in 1987 by the Bank of England, is an international trade association, representing the London market for gold and silver bullion which has a global client base and being traded on a 24-hour basis mainly through London in OTC transactions in spot, forwards and options. The TOCOM (Tokyo Commodity Exchange) formed by the Tokyo Gold Exchange, the Tokyo Rubber Exchange and Tokyo Textile Exchange in 1984, is one of the most prominent commodity futures exchanges in Asia. The NYMEX, a commodity futures exchange owned and operated by CME Group of Chicago, was merged by two principal divisions, NYMEX (New York Mercantile Exchange) and COMEX (Commodity Exchange, Inc.) on August 3rd, 1994. Gold futures are listed on the COMEX and platinum on the NYMEX.

In this paper, Using intraday prices data of gold and platinum, we calculate each measures of microstructure characteristics (such as price discovery and market liquidity), to investigate the contributions to price discovery among three main markets of gold (COMEX, LBMA and TOCOM), also FX futures contracts between U.S. and Japan; to examine the intraday seasonality of informational efficiency, return volatility, trading volume and market liquidity in the platinum and gold futures markets on exchanges in Tokyo and New York; and to analysis intraday relationships between liquidity and arbitrage, and liquidity and price discovery in the markets for platinum futures in Tokyo and New York.

In Chapter 2, we examine a multivariate VECM (vector error correction model) to investigate the contributions to price discovery in gold futures from the New York, London and Tokyo markets, also FX futures contracts between U.S. and Japan. Two conclusions are implied by our results. First, although pricing transmissions for gold futures contracts are rapid across the three major gold markets, price discovery is still dominated by LBMA among the three markets, and UK information appears to play a leading role to the U.S. and Japanese markets during the sample period, because of the dominance of London market as major trading center of gold with largest volume. Second, for the gold futures and FX markets between U.S. and Japan, both measures show that the COMEX dominate other two markets in price discovery.

In Chapter 3, we investigate intraday seasonality in, and relationships between, informational efficiency, volatility, volume and liquidity. Platinum and gold, both traded in overlapping sessions in Tokyo and New York, provide an interesting comparison because Tokyo is an internationally important trading venue for platinum but not for gold. Our analysis indicates that both platinum and gold markets in Tokyo are dominated by uninformed trading, while there is evidence supporting both uninformed and informed trading in New York. Separating global trading hours into Tokyo, London and New York day sessions, we also find that uninformed trading is more prevalent during the Tokyo day session while informed trading dominates the New York day session for both metals in both locations. This evidence suggests that futures markets for the same underlying commodity on different exchanges have different microstructure characteristics, while both informed and uninformed traders choose when to trade depending on market characteristics in different time zones.

In Chapter 4, we use a SEM (simultaneous equation model) with the 3SLS (three-stage least squares) to estimate intraday relationships between liquidity and arbitrage, and liquidity and price discovery in the markets for platinum futures in Tokyo and New York. Two conclusions are implied by our results. First, an increase in arbitrage activity is associated with a reduction in market liquidity imbalance between Tokyo and New York, while an improvement in liquidity difference leads to increased arbitrage profit. This finding provides support for the view that arbitrageurs tend to trade against temporary demand shocks and thus enhance market integration and liquidity. Second, an increase in liquidity in one market relative to another increase the contribution of that market to price discovery, which implies that the market which provides better liquidity will become more important in terms of price discovery. This impact occurs within the same day session intervals. Conversely, an increase in price discovery leads to improved liquidity, indicating that the market which leads in terms of price discovery attracts more liquidity.

Chapter 2. Price discovery in Gold Futures Markets

2.1 Introduction

Investors generally buy gold as portfolio diversification, inflation and currency hedge and risk management, because gold are not only low correlate to many equity markets and less volatile than most commodities, but also can diversify risk and retain long term purchasing power. Gold and platinum are traded OTC (over-the-counter) worldwide and financial precious metals products, such as ETFs (exchange-traded funds), futures and other derivatives on a wide variety of organized exchanges and platforms. Understanding the price formation process and where/how information about the value of gold is impounded into its price is paramount to investors and regulators due to the economic significance of gold.

Gold price is affected by not only domestic supply and demand factors in Japan but also the overseas factors. Because gold have standard quality and storage characteristics that enable arbitrage in cross-market futures trading, price deviations occured on organized exchanges worldwide will be resolved by arbitrage trading of speculators. While the international information about the price of gold transmitted from other markets, how the Japanese gold price will be reflected. "Which market plays a leading role in setting the gold price" is an important issue not only in lead-lag relationships among the markets but also in the price efficiency determination.

In this chapter, we investigate price discovery among gold markets. Price discovery is one of the central functions of financial markets. Booth et al. (1999) defined price discovery is the dynamic process by which markets incorporate new information to arrive at equilibrium asset prices. Baillie et al. (2002) considered price discovery as news being gathered and interpreted in multiple markets. Yan and Zivot (2010) illustrated that the important issues of price discovery are determining which market first incorporate new information about the implicit asset, and how the efficacy of price discovery depends on trading mechanisms, market liquidity, and the prevalence of asymmetric information. Using intraday synchronous 1-minute price data from the New York, London and Tokyo gold markets, to examine the information of which market captures have the most influence on the gold efficient price. Using the gold spot price from the LOTC (London over-the-counter) spot market called Loco London, which plays a more important role in worldwide gold trading, and the gold futures price from the COMEX (Commodity Exchange, a division of the New York Mercantile Exchange) in U.S. and TOCOM in Japan, We employ high-frequency time-series analysis to examine price discovery. The price of London and New York is Dollar based, as the price of Tokyo is Yen based, we need to convert it to Dollar based by using the USDJPY exchange rate.

As homogeneous goods, the gold prices in London, New York, Tokyo is expected to follow the Law of one Price, that "a good must sell for the same price in all locations", but not strictly. Futures prices would always be higher than spot prices and converge upon spot prices during the delivery month. Also, market efficiency describes the arrival speed of market consensus or equilibrium price, there are many possible explanations why observed asset prices generally depart from their underlying efficient values. One of rational explanations is the existence of market frictions and the limitation of investors to process information set with precision. District transaction costs, regulations, liquidities, and other institutional factors make different contribution to price discovery. An important difference between the Tokyo and New York futures markets for both platinum and gold is the most actively traded maturity. In New York, as with most commodity futures markets, nearby contract months are the most actively traded, while deferred contract months tend to be inactively traded. As noted in Kang et al. (2011), platinum and gold in Tokyo are actively traded in deferred contract months and inactively traded in nearby contract months.

Gramming, Melvin and Schlag (2005) analyze exchange rates along with equity quotes for 3 German firms from New York (NYSE) and Frankfurt (XETRA) during overlapping trading hours to see where price discovery occurs and how stock prices adjust to an exchange rate shock, they find that the exchange rate is exogenous with respect to the stock prices and exchange rate innovations are more important in understanding the evolution of NYSE prices than XETRA prices. Levine and Wright (2006), Oxford Economics (2012) have adopted an error correction format to model that were used to identify the key determinants of the price of gold, the results shows that the effective Dollar exchange rate is statistically significant with a negative sign. As a result, a falling dollar increases the purchasing power of non-dollar area countries driving up prices of commodities including gold; in periods of dollar weakness, investors look for an alternative store of value, driving up gold prices. As investors in TOCOM are Yen based which is different from the Dollar based traders in COMEX, and the gold prices in Tokyo and New york do not follow the LOP strictly, so that the USDJPY exchange rate can be considered as an important determinant of gold price, and error-correcting price adjustment also occurs on FX exchange in maintaining cross-market equilibrium between U.S. and Japan.

There are two competing definitions of the contribution to price discovery in market microstructure models. IS measures (the information shares) defined in Hasbrouck (1995) gives us upper and lower bounds for these shares, that focused on the variance of the efficient price innovation. In contrast, GG measures (the common factor component weight) of Gonzalo and Granger (1995) provides a unique level, that focused on the components of common factor and the error correction processes,. Both measures are based on VECM (vector error correction model). Baillie et al. (2002) showed that the two models are directly related and provide similar results if the residuals are uncorrelated between markets. de Jong (2002) also demonstrated that the two measures are closely related, but that only the information share takes in to account the variability of innovations in each market's price. Lehmann (2002) found that the Hasbrouck information shares decompose the variance of efficient price changes into components attributable to different markets with unavoidable ambiguity when price change innovations are correlated across markets, which emphasized that the interpretation of IS and GG measures of price discovery is not always clear, because they are based on the residuals from a reduced form VECM. Therefore, Yan and Zivot (2010) used a structural co-integration model in which the sources of shocks are identified, to define unambiguous measures of price discovery that capture the full dynamic process of how new information impacts prices.

Although there are a number of literatures investigating price discovery process, the majority of articles examined in the equity index markets. Harris et al. (1995) used synchronous transaction data for IBM from the New York, Pacific and Midwest Stock Exchanges and a two cointegration and error correction model, to investigate the nature and extent to which regional exchanges contribute to the price discovery process. This paper demonstrated that equilibrium IBM prices are established by information revealed across the three markets, and two error correction terms specified as the price differentials relative to the NYSE indicate that adjustment maintaining the long-run cointegration equilibrium take place on all three exchanges. Booth et al. (1999) investigated the intraday price discovery process among stock index, index futures, and index options in Germany using DAX index securities and intraday transaction data. In terms of contributions to information, the index futures are found to be dominant, whereas index options contributes least. Moreover, the results support the transaction costs hypothesis, because of the lowest trading costs in the FDAX of the three markets. Hasbrouck (2003) employed high-frequency time-series analysis to reexamine index price discovery in three important U.S. equity index markets. The results suggest that for the S&P 500 and Nasdaq-100 indexes, price discovery is still dominated by E-minis (electronically traded, small-denomination futures contracts), while the E-minis have a smaller size than the pit-traded contracts, and trade on the CME's GLOBEX electronic limit order book system. The results are less clear for the S&P MidCap 400 index where no E-minis existed over the sample period, that suggest dominance of the ETFs.

Then getting back to the papers about gold futures markets. Bhar and Hamori (2004) examined the pattern of information flow between the percentage price change and the trading volume in gold futures contracts by using daily data from January 3, 1990 to December 27, 2000. They find evidence of strong contemporaneous causality in variance indicating the mixture of distribution hypothesis of information flow, which is estimated by both the original and augmented AR-GARCH model. Lagged causality running from percentage price change to trading volume also support for the sequential information flow hypothesis, that is probably due to some special characteristics of gold as a commodity, particularly when the equity market underperforms. Xu and Fung (2005) used a bivariate asymmetric GARCH model to examine patterns of across-market information flows for precious metals futures contracts from November 1994 to March 2001 traded in both the U.S. and Japanese markets. The results indicate that the pricing transmission across both markets is strong and rapid, and U.S. information appears to play leading role to the Japanese market. Lucey et al. (2013) investigated the information share by using COMEX and LBMA gold prices from January 1986 through the end of July 2012. They find that neither London nor New York are dominant, and price discovery is unstable, because the dominant market switches from time to time, and do not show obvious linkage to particular or routine political events.

The empirical application of this chapter focuses on not only the pricing transmissions across U.S., UK and Japanese gold futures markets (COMEX, LBMA and TOCOM), but also the cross-market linkages between gold and FX futures trading in U.S. and Japan. To accomplish this purpose, I use a multivariate VECM, which presupposes cointegration, permits exploration of price discovery relationships. The remainder of this chapter is organized as follows. In Section 2, the methodology is presented, while Section 3 illustrates how intraday synchronous trading data is constructed. Section 4 describes the empirical findings. A brief summary concludes the chapter in Section 5.

2.2 Methodology

2.2.1 Multivariate VECM

It is now well accepted to use a VECM to describe the relationships exhibited by cointegrated asset prices. This is also the approach used to model the interactions among three markets. Both the IS and GG models start from the estimation of the following VECM:

$$\Delta p_t = \mu + \alpha\beta' p_{t-1} + \sum_{k=1}^{n} A_k \Delta p_{t-k} + e_t \qquad (2.1)$$

where $p_t = (p_{1t}, p_{2t}, p_{3t})$ represent the log-prices of the three markets, which are closely linked by arbitrage, and I(1) (integrated of order 1), so that the difference Δp_t are the respective returns at time t and stationary.

The VECM has two portions: the second term $\alpha\beta' p_{t-1}$ represents the long-run or equilibrium dynamics between the price series, and the third term $\sum_{k=1}^{n} A_k \Delta p_{t-k}$ describes the short-run dynamics induced by market imperfections. Harris et.al (1995) emphasized that the error correction dynamics involve only cross-market information flows displayed by adjustments to price difference across the three markets.

The vector α contains the error correction coefficients, and $z_{t-1} = \beta' p_{t-1}$ is the error correction term, which is stationary, therefore, β is considered a linear basis for the set of cointegrating vector, and k is the lag length determined by AIC. The α coefficients interpret as speed of adjustment. The μ in the error correction term is a vector of mean errors and captures systematic differences in the prices. From an economic perspective, the mean error is the target of the adjustment process. Moreover, $e_t = (e_{1t}, e_{2t}, e_{3t})$ is a zero-mean vector of serially uncorrelated innovations with the 3×3 symmetric covariance matrix Ω such that,

$$\Omega = \begin{pmatrix} \sigma_1^2 & \rho_{12}\sigma_1\sigma_2 & \rho_{13}\sigma_1\sigma_3 \\ \rho_{12}\sigma_1\sigma_2 & \sigma_2^2 & \rho_{23}\sigma_2\sigma_3 \\ \rho_{13}\sigma_1\sigma_3 & \rho_{23}\sigma_2\sigma_3 & \sigma_3^2 \end{pmatrix} \quad (2.2)$$

σ_i^2 is the variance of e_{it} and ρ_{ij} is the conditional correlation between error terms e_{it} and e_{jt}, $(i, j = 1,2,3; i \neq j)$.

2.2.2 Hasbrouck's IS measures

Hasbrouck (1995) introduced the information shares for measuring a given market's contribution to price discovery. This approach defines the information share of a market as the proportion of the efficient price innovation variance that can be attributed to that market. Then the VECM Eq. (2.1) is transformed into a VMA (vector moving average),

$$\Delta p_t = \Psi(L)e_t \quad (2.3)$$

since $\Psi(L) = \sum_{j=0}^{\infty} \Psi_j L^j$, so that its integrated form is:

$$p_t = p_0 + \Psi(1)\sum_{s=1}^{t} e_s + \Psi^*(L)e_t \quad (2.4)$$

where $\Psi(L)$ and $\Psi^*(L)$ are matrix polynomials in the lag operator, L. The impact matrix, $\Psi(1)$, is the sum of the moving average coefficients, which contains the cumulative impacts of the innovation e_t on all future price movements, and thus measures the long-run impact of e_t on each of the prices. In Eq. (2.4), $\Psi(1)\sum_{s=1}^{t} e_s$ is the component of the price change that is permanently impounded into the price and is presumably due to new information, and $\Psi^*(L)e_t$ is the transitory portion.

As error correction term $z_{t-1} = \beta' p_{t-1}$ is stationary, and the $\sum_{s=1}^{t} e_s$ is non-stationary, the Granger representation theorem (Engle and Granger, 1987) states that the co-integrating vector β and the cumulative impacts matrix $\Psi(1)$ satisfies $\beta'\Psi(1) = 0$. If the rows of the impact matrix $\Psi(1)$ are identical, as a result, the long-run impacts of an innovation e_t are the same for all prices. If we denoted $\psi = (\psi_1, \psi_2, \psi_3)$ as the common row vector of $\Psi(1)$, Eq. (2.4) becomes,

$$p_t = p_0 + \iota\psi \sum_{s=1}^{t} e_s + \Psi^*(L)e_t \qquad (2.5)$$

where $\iota = (1,1,1)'$. The results are primarily derived from $\alpha_\perp = (\gamma_1, \gamma_2, \gamma_3)$, which is the orthogonal to the error correction coefficient vector α. Moreover, the following equations can be observed,

$$\Psi(1) = \beta_\perp \Pi \alpha_\perp{}' \qquad (2.6)$$

$$\Pi = (\alpha_\perp{}'(I - \sum_{k=1}^{n} A_k)\beta_\perp)^{-1} \qquad (2.7)$$

where $\beta_\perp$ is the orthogonal matrices to β, and I is the identity matrix, with Π being a scalar if there is only one common factor in the system.

If Ω is diagonal (the market innovations are uncorrelated) then $\psi\Omega\psi'$ will consist of 3 terms, each of which represents the contribution to the common factor innovation from a particular market. The market i's information share is defined as,

$$IS_i = \frac{\psi_i^2 \sigma_i^2}{\psi\Omega\psi\prime} \qquad (2.8)$$

where ψ_i is the ith element of ψ, and σ_i^2 is the ith diagonal element in Ω. From equation it is clear that a high (low) IS for market i implies a large (small) response to the arrival of new information about fundamental value.

However, if the price innovations are correlated across markets, the Ω will not be diagonal. In this case, Hasbrouck (1995) suggested to compute the Cholesky decomposition of $\Omega = FF'$ to eliminate the contemporaneous correlation, and measure the IS using the orthogonalized innovations, where F is a lower triangular matrix. Then the market i's information shares are given as follows:

$$IS_i = \frac{([\psi F]_i)^2}{\psi\Omega\psi'} \qquad (2.9)$$

where $[\psi F]_i$ is the ith element of the row matrix ΨF. it can be seen that, the upper (lower) bound of IS_i is obtained with the ith price being first (last) in the sequence, while assuming the cross correlation is positive.

2.2.3 Gonzalo and Granger's GG measures

Gonzalo and Granger (1995) proposed using the permanent-transitory decomposition of p_t to measure a market's contribution to price discovery. The specification is closely related to the common trend representation found in Stock and Watson (1988),

$$p_t = f_t + g_t \qquad (2.10)$$

where the common vector f_t is the permanent part and I(1), and g_t is the transitory part and stationary. Gonzalo and Granger (1995) assume that there is no long-run Granger causality from g_t to f_t, and define the common vector f_t to be a linear combination of the prices p_t,

$$f_t = \gamma' p_t \qquad (2.11)$$

where $\alpha_\perp = (\gamma_1, \gamma_2, \gamma_3)$, the orthogonal matrices of α. As a result, the GG measures can also be defined in terms of the elements of γ as,

$$GG_i = \frac{|\gamma_i|}{|\gamma_1| + |\gamma_2| + |\gamma_3|} \qquad (2.12)$$

2.3 Data

This section provides an overview of the three main gold futures markets (COMEX, LBMA and TOCOM) in this Chapter, the listed gold futures date quotes among the U.S., UK and Japanese markets are not simultaneous. The “daylight” issue with non-overlapping data is common to all studies of international financial markets. For gold futures trading hours, COMEX operates from 6:00 p.m. to 5:15 p.m. (New York Time/NYT) with a 45-minute break each day beginning at 5:15 p.m.. LBMA is traded on a 24-hour-basis, mainly through London, in OTC transactions in gold futures. TOCOM’s trading hours continued from 9:00 a.m. to 3:30 p.m. (JST) for the day session and from 5:00 p.m. to 4:00 a.m. (JST) for the night session. As TOCOM extends trading hours for the night session until 4:00 a.m. (JST) in September, 2010, which overlapped with most of the daytime trading hours in London, it becomes more convenient for market participants around the world to arbitrage between New York, London and Tokyo. Thus, this measure would greatly push forward TOCOM’s efforts for promoting its markets among overseas market participants. To construct overlapped time series data set, I use 1-minute data set from 5:00 p.m. to 4:00 a.m. (JST), 11 hours, all the night session in TOCOM. My study covers the period from March 2014 to July 2014. If any of the markets experience holidays or missing data intervals, the data for those days or intervals will be omitted for all three markets. Since Daylight Saving Time is adopted in New York and London, the JST hours corresponding to the local business hours of New York and London by one hour during their respective summer season. In 2014, Summer Time is March 9-November 2 in New York and March 30-October 26 in London.

Both U.S. and UK’s gold futures contracts are traded in the price quotation U.S. Dollars per troy ounce, while the price increment in Japan is JPY per gram. The 1-minute prices of the gold futures in Japan are adjusted to U.S. Dollars per troy ounce, using the 1-minute USDJPY (Japanese Yen/U.S. Dollar) exchange rate provided by Reuters, and 1kg/contract (approximately 32.15 troy ounces). Therefore, all gold futures prices are expressed in terms of U.S. Dollars per troy ounce for comparison. There are 53,460 observations remained by these adjustments. All the price series after being transformed to logarithms are I(1) variables, making the first differences of their log-price (continuous return) stationary. Several statistics describing the bid, ask and log-price series are provided in Table 2.1, which supports the presence of arbitrage opportunities among the three gold future markets suggests that their prices should not drift top far apart in the long-run.

Table 2.1 Summary Statistics

	Min.	Median	Max.	Mean	S.D.
Mid_US	7.125	7.170	7.234	7.169	0.020
Mid_UK	7.124	7.169	7.232	7.168	0.020
Mid_JP	7.126	7.170	7.233	7.169	0.020
USDJPY	4.614	4.624	4.645	4.625	0.006

2.4 Empirical Results

2.4.1 Price discovery among the U.S., UK and Japanese gold futures markets

The Johansen test results for the three gold log-price series obtained with the data sets shows that the three log-prices are co-integrated with a co-integrating vector, and the eigenvector corresponding to the first eigenvalues is the co-integrating vector representing the empirical long-run relationship among Mid_US, Mid_UK and Mid_JP. The equilibrium error relationship implied by the cointegrating vector is,

$$z_t = Mid\_US_t + 5.068Mid\_UK_t - 6.163Mid\_JP_t \qquad (2.13)$$

Using AIC (Akaike information criterion) to determine the appropriate length of lags, I choose the final models from various possible VECM specifications. For gold futures contracts in COMEX, LBMA and TOCOM, the computed smallest AIC equals to 13, and hence 13-lag model was selected and reported as the appropriate model.

Table 2.2 VECM Estimation Results

Dependent Variables			
	Mid_US	Mid_UK	Mid_JP
Mid_US(-1)	-0.549(-15.176***)	0.287(8.010***)	0.257(7.379***)
Mid_US(-2)	-0.567(-12.034***)	0.121(2.591**)	0.092(2.033*)
Mid_US(-3)	-0.675(-12.692***)	-0.038(-0.726)	-0.016(-0.319)
Mid_UK(-1)	0.564(14.596***)	-0.268(-6.993***)	0.371(9.965***)
Mid_UK(-2)	0.555(11.169***)	-0.125(-2.530*)	0.335(7.007***)
Mid_UK(-3)	0.647(11.620***)	0.016(0.297)	0.319(5.950***)
Mid_JP(-1)	-0.012(-0.806)	-0.018(-1.195)	-0.651(-45.157***)
Mid_JP(-2)	0.013(0.744)	0.002(0.123)	-0.441(-25.937***)
Mid_JP(-3)	0.028(1.509)	0.018(0.955)	-0.314(-17.311***)
Mid_JP(-5)	-0.045(-2.296*)	-0.055(-2.830**)	-0.253(-13.335***)
Mid_JP(-13)	0.034(2.328*)	0.031(2.106*)	0.008(0.549)
Constant	5.014e-04(1.379)	4.601e-04(1.277)	1.287e-03(3.676***)
ECT	7.329e-04(1.382)	6.727e-04(1.281)	1.879e-03(3.680***)

Notes:
Estimates (t-statistics) are indicated for each variable.
Significance levels: '***' 0.01 '**' 0.05 '*' 0.1.

Table 2.2 provides the VECM results, I reported only the coefficients of the first three lagged ΔMid_US, ΔMid_UK and ΔMid_JP terms, constant and error correction terms. The coefficients of lagged ΔMid_US and ΔMid_UK are significant, while being insignificant for ΔMid_JP, so I hypothesize that the COMEX and LBMA may affect the TOCOM directly and the TOCOM may not have strong influence on the COMEX and LBMA, although informative. In other words, the TOCOM do not provide useful information for the spring of the COMEX and LBMA. As the coefficients of fifth and thirteenth lagged ΔMid_JP terms are significant, I also hypothesize that the TOCOM reacts faster with respect to the COMEX and LBMA than the COMEX and LBMA to the TOCOM. Both hypotheses are consistent with the results of Xu and Fung (2005). However, only the coefficients associated with the ΔMid_JP regression, α_3 is statistically significant and positive, this means that the TOCOM use the COMEX and LBMA to represent the new equilibrium price by the arrival news.

Table 2.3 reports IS and GG measures among the three markets. The IS measures are estimated six times by change the order of three variables, then take the average of upper and lower bound of each market. Both IS and GG measures confirm that the LBMA captures the most contribution to price discovery among the three markets, then COMEX, and TOCOM contributes least. This suggests that the LBMA dominate the other two markets in price discovery, and is a global leader in the gold futures markets during the period from March to July in 2014, which also indicates some support for the hypothesis from Table 2.2.

Table 2.3 Price Discovery Measures

	COMEX	LBMA	TOCOM
IS measures	35.1%	36.6%	28.2%
GG measures	28.7%	46.9%	24.4%

2.4.2 Price discovery for the gold futures and FX markets between U.S. and Japan

In this section, I model the dynamics of the log-price in COMEX, TOCOM and the USDJPY change also using VECM process to investigate the contribution of USDJPY exchange rate in price discovery. Similar to the previous analysis process, to obtain the AIC computing and Johansen test results, the 13-lag and one cointegrating vector model is required,

$$z_t = Mid\_US_t + 1.062USDJPY_t - 1.024Mid\_JPY_t \qquad (2.14)$$

$$Mid\_JPY_t = Mid\_JP_t + USDJPY_t \qquad (2.15)$$

The estimated VECM in Table 2.4 yields a number of important observations. First, with the error correction terms included, most of the first three lagged Then ΔMid_US, $\Delta USDJPY$ and ΔMid_JP are now significant, which suggests that pricing information transmissions for these gold futures contracts are strong and rapid across the three markets. Second each of the coefficient estimates on the lagged z_{t-1} terms is also statistically significant, which is required for a long-run equilibrium to exist. In other words, error-correcting price adjustment occur on all three exchanges in maintaining cross-market equilibrium. This means, with the gold and FX futures markets adjust to restore equilibrium, when the cointegrating relationship is perturbed by the news arriving. Looking at the magnitudes of the coefficients on z_{t-1} in each equation provides several specific insights into the error correction process. In arriving at the new equilibrium price, all three futures markets adjust with respect to each other as well, and the TOCOM responds faster than the other two exchanges, because of the larger ECT coefficient.

Table 2.4 VECM Estimation Results

Dependent Variables			
	Mid_US	USDJPY	Mid_JPY
Mid_US(-1)	-5.522e-02(-4.015***)	-3.114e-02(-5.623***)	5.528e-01(44.935***)
Mid_US(-2)	-5.955e-02(-3.622***)	-1.335e-02(-2.017*)	3.892e-01(26.466***)
Mid_US(-3)	-8.206e-02(-4.644***)	-2.478e-02(-3.483***)	2.598e-01(16.440***)
USDJPY(-1)	-5.612e-02(-3.445***)	-9.949e-02(-15.165***)	4.859e-01(33.340***)
USDJPY(-2)	-6.884e-02(-3.706***)	-3.803e-02(-5.084***)	3.668e-01(22.075***)
USDJPY(-3)	-9.469e-02(-4.807***)	-1.942e-02(-2.449*)	2.512e-01(14.255***)
Mid_JPY(-1)	5.657e-02(3.871***)	2.827e-02(4.804***)	-5.852e-01(-44.761***)
Mid_JPY(-2)	6.011e-02(3.453***)	1.153e-02(1.644)	-4.067e-01(-26.117***)
Mid_JPY(-3)	7.891e-02(4.230***)	2.612e-02(3.477***)	-2.747e-01(-16.462***)
Constant	-6.378e-06(-2.147*)	3.153e-06(2.636**)	-8.833e-06(-3.324***)
ECT	5.764e-03(2.008*)	-3.421e-03(-2.960**)	8.357e-03(3.256**)

Notes:
Estimates (t-statistics) are indicated for each variable.
Significance levels: '***' 0.01 '**' 0.05 '*' 0.1.

Both the results of the Hasbrouck (1995) and Gonzalo and Granger (1995) model given in Table 2.3. As shown in the table, in terms of contributions to information, the COMEX is found to be the main driving force, whereas USDJPY exchanges and the TOCOM contributes less. Moreover, the results suggest that COMEX play relatively more important role than FX futures contracts and the TOCOM in price discovery. The ordering of FX futures markets and TOCOM has been changed that TOCOM has a larger IS measures, but in GG measures, USDJPY is larger. This is probably due to the negative correlation between ΔMid_US and $\Delta USDJPY$, so that the upper bound of USDJPY will be decreased by the IS measures' calculating process, while being shared by the own innovations.

Table 2.3 Price Discovery Measures

	COMEX	USDJPY	TOCOM
IS measures	37.8%	27.7%	34.5%
GG measures	40.9%	35.9%	23.2%

2.5 Conclusions

In this Chapter, We employ high-frequency time-series analysis to examine price discovery in the COMEX, LBMA and TOCOM gold futures contracts, also for gold and FX futures markets between U.S. and Japan. The intraday synchronous 1-minute price data from March to July in 2014 are applied to identify the lead-lag relationships among the markets. Both Hasbrouck's (1995) IS measures and Gonzalo and Granger's (1995) GG measures are estimated to definite the contribution to price discovery in market microstructure models. The VECM is used to describe the relationships exhibited by cointegrated asset prices. Two conclusions are implied by the paper's results. First, We find that price discovery is still dominated by LBMA among the three markets, and UK information appears to play a leading role to the U.S. and Japanese markets during the sample period, because of the dominance of London market as major trading center of gold with largest volume. Second, for the gold futures and FX markets between U.S. and Japan, both measures show that the COMEX dominate other two markets in price discovery.

Chapter 3 Intraday Seasonality in Efficiency, Liquidity, Volatility and Volume: Platinum and Gold Futures in Tokyo and New York

3.1 Introduction

Why do multiple exchanges that trade the same commodity exist? A number of futures exchanges have extended their trading hours to include night sessions, overlapping with each other. It is now common for different exchanges to trade futures based on the same underlying commodity at the same time. Arbitrage activity, assisted by the globalisation of commodity markets and advances in trading technology, encourages commodity futures mid-prices on different exchanges to be virtually identical after adjusting for contract specifications and exchange rates. A straightforward argument would suggest that market participants prefer to trade on the exchange with superior price discovery, efficiency and liquidity. Therefore, trade in the futures of a particular commodity would be expected to agglomerate to one exchange, as higher liquidity and scale economies encourage traders to the venue. However, multiple futures exchanges persist for many commodities.

In this chapter, we aim to shed light on why this may be the case. We investigate whether markets for commodities futures contracts on different exchanges have different microstructure characteristics. Such differentiated characteristics may be advantageous for certain investors, and provide a competitive advantage for the exchange. We address this question by estimating and comparing the intraday seasonality of informational efficiency, volatility, volume and liquidity in platinum and gold futures traded in overlapping sessions on exchanges in Tokyo and New York.

Platinum and gold futures are traded on the Tokyo Commodity Exchange (TOCOM), while in New York, platinum futures are listed on the New York Mercantile Exchange (NYMEX) and gold on the Commodity Exchange, Inc. (COMEX). Historically, TOCOM has been an important global venue for trading platinum futures. In the past, activity in the global market for platinum has been heavily influenced by the hedging trades of large industrial end consumers of platinum metal in Japan who access the futures market via TOCOM. Until recently, the total weight of platinum represented by futures traded on TOCOM far outweighed that of NYMEX. In 2008 for example, 3.5 million kilograms was traded on TOCOM[1], or 4.4 times that of NYMEX. However, annual volume on the Tokyo market has been in long-term decline, down from over 16 million contracts in 2001 to just over 3.1 million contracts in 2016 (including both the platinum standard and mini contracts). In 2015 NYMEX was about 2.9 times larger than Tokyo by weight of platinum, and 4.2 times larger in 2016. However, in terms of contract volume, monthly turnover in Tokyo usually exceeds that of New York (see Figure 3.1). The TOCOM contract unit is 500 grams or 16.08 troy ounces of metal for the standard future and 100 grams for the mini contract, versus the NYMEX standard specification of 50 Troy ounces[2]. Despite the decline in TOCOM volume, a not insubstantial share of the global platinum futures trade still occurs on the exchange. Important end users of physical platinum continue to use TOCOM futures for hedging. Global futures trade in platinum is concentrated on the two venues TOCOM and NYMEX. This contrasts with gold, for which TOCOM's annual futures turnover by weight of metal is small compared to that on COMEX. As also shown in Figure 3.1, COMEX gold turnover by number of contracts still dwarfs that on TOCOM despite the COMEX contract being 100 troy ounces compared with 1 kilogram or about 32.15 troy ounces for the TOCOM standard contract. Gold pricing is considered driven by global risk and monetary factors, and trading is decentralised (Hauptfleisch et al., 2016). Further, there are no features of the gold business in Tokyo that would suggest the location is particularly important in the determination of global gold futures prices. Tokyo gold futures trade

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[1] Refer to http://www.tocom.or.jp/historical/dekidaka.html for TOCOM trading volume.

[2] TOCOM contract specifications can be found at http://www.tocom.or.jp/guide/youkou/platinum.html and http://www.tocom.or.jp/guide/youkou/gold.html, NYMEX at http://www.cmegroup.com/trading/metals/files/platinum-and-palladium-futures-and-options.pdf, and COMEX at http://www.cmegroup.com/trading/metals/precious/gold_contractSpecs_futures.html.

represented about 6 percent and 5 percent of COMEX trade by weight in 2015 and 2016, respectively. Accordingly, platinum and gold futures traded in Tokyo and New York provide an interesting comparison for the analysis of intraday microstructure patterns.

[Insert Figure 3.1 here]

TOCOM has become a more internationalised market over time. Trade orders originating outside Japan have been an increasing proportion of total trade on TOCOM since May 2009 after the exchange launched a new trading platform and night session (TOCOM, 2015). International buy and sell orders make up a substantial portion of both the platinum and gold trade on TOCOM during our sample period[3]. Foreign buy and sell trades in the platinum market made up approximately 36 percent and 45 percent of the total in 2014 and 2015, respectively. The proportion of foreign transactions in the gold market was higher, with 46 and 51 percent of both buy and sell trades in 2014 and 2015, respectively. Most foreign orders over this period originated from the United States, Australia, Singapore and Hong Kong.

An important difference between the Tokyo and New York futures markets for both platinum and gold is the most actively traded maturity. In New York, as with most commodity futures markets, nearby contract months are the most actively traded, while deferred contract months tend to be inactively traded. As noted in Kang et al. (2011), platinum and gold in Tokyo are actively traded in deferred contract months and inactively traded in nearby contract months. Our analysis uses data for the most liquid contract month for each metal on each exchange. Accordingly, we use the nearby contract months for platinum and gold in New York, and the deferred contract months for platinum and gold in Tokyo. Although this introduces a maturity mismatch, we do not believe this makes a material difference to our analysis. We are interested in comparing the microstructure

[3] Data on foreign customer transactions is obtained from http://www.tocom.or.jp/jp/historical/download.html.

characteristics of the most actively traded contract for each metal and exchange. Tokyo platinum contract trading volume in the deferred contract exceeds that of New York in the nearby and the deferred contracts (Kang et al. 2011). Indeed, part of the differentiation between exchanges that may be advantageous to a trader transacting in Tokyo is the longer horizon on a market with reasonable liquidity.

Tokyo conducts an evening trading session that runs in parallel with most of the New York day session. New York is also open for trade during the Tokyo day session. Do these markets follow their own distinct intraday patterns in efficiency, liquidity, volatility and volume, or do they have a common seasonality? Do relationships between microstructure characteristics suggest informed[4] or uninformed trading on these exchanges? We estimate a regression model for intraday seasonality in each microstructure characteristic for each metal on each exchange, and use the estimates to investigate the extent to which the markets on each exchange follow a common intraday seasonal pattern. We also analyse the intraday relationships between informational efficiency and return volatility, trading volume and liquidity for indications on the prevalence and patterns of informed versus uninformed trading in the platinum and gold markets.

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[4] We differentiate between informed and uninformed traders as is typical in microstructure modelling (de Jong and Rindi, 2009). Informed traders use costly private information about the future value of the asset traded with the aim of transacting for a profit. This information may be research on the asset's expected future value, knowledge of order flow in the market, or inside information. Uninformed traders such as liquidity traders, noise traders and hedgers do not possess such private information. Liquidity traders transact only for liquidity reasons which are not related directly to the future payoffs of financial assets. Noise traders transact for reasons neither based on liquidity nor fundamental information. Hedgers trade to mitigate risks that arise from holding other correlated assets. Uninformed traders, particularly liquidity traders, may or may not have discretion over the timing of their transactions.

We find similarities in intraday informational efficiency and return volatility patterns between futures for the same metal traded on different exchanges, and differences in volume and liquidity patterns. Relationships between these patterns suggest that, over global trading hours, the Tokyo markets for platinum and gold are dominated by uninformed trading, while there is evidence of both uninformed and informed trading in New York. During Tokyo's daytime session, the markets for platinum and gold in both Tokyo and New York display uninformed trading characteristics. Conversely, both markets for both metals have characteristics consistent with informed trading over the hours of New York's daytime session. Our analysis suggests that both informed and uninformed traders choose when to trade depending on market characteristics in different time zones.

The chapter proceeds as follows. In the next section, we summarise relevant literature on intraday patterns in informational efficiency, volatility, volume and liquidity in financial markets, and the intraday relationships between informational efficiency and volatility, volume and liquidity. In section three, we describe our platinum and gold data and the regression model. In section four, we present and discuss our empirical results, and section five concludes.

3.2 Review of Previous Research

3.2.1 Intraday Seasonality

Researchers have long sought to confirm the existence of intraday seasonality in security prices and explain persistent intraday patterns in market microstructure characteristics such as return volatility, trading volume and liquidity. Most studies conducted during and after the 1990s analyse intraday patterns over the daytime trading sessions in equity markets, while few studies examine those in commodity markets.

Intraday trading volume and return volatility are typically characterised as following a U-shaped pattern in empirical studies. Both volume and volatility tend to be relatively high at market open, relatively low for most of the trading day, and rise into the close. Equity return volatility is shown to have a U-shaped pattern over the day in Harris (1986), Lockwood and Linn (1990), McInish and Wood (1990a), Werner and Kleidon (1996) and Abhyankar et al. (1997). Similarly, equity trading volume has an intraday U-shaped pattern in Jain and Joh (1988), McInish and Wood (1990b), Brock and Kleidon (1992) and Chan et al. (1995). Intraday patterns have been described as a reverse-J for some markets, where volume or volatility ahead of the close remains substantially lower than at the open but higher than for the middle of the trading day. Hussain (2011) reports a reverse J-shaped pattern in DAX index return volatility, while Harju and Hussain (2011) show the same type of pattern in other European equity indices. Further, L-shaped patterns have been observed in markets where volume or volatility fails to rise at the end of the trading day, such as for trading volume in DAX30 equities (Hussain, 2011). Abhyankar et al. (1997) report an M-shaped pattern for trading volume in UK stocks.

Bid-ask spreads, a proxy for market liquidity, have also been shown to exhibit intraday U-shaped or reverse-J patterns. Brock and Kleidon (1992) find U-shaped bid-ask spread patterns in US equities, while Ahn and Cheung (1999) and Ahn et al. (2002) discover U-shaped patterns in Hong Kong and Japanese equities, respectively. Theissen and Freihube (2001) and Hussain (2011) document reverse-J shaped intraday bid-ask spread patterns in German equities, while Abhyankar et al. (1997) find the same shape in UK equities. Although McInish and Wood (1992) provide evidence of a reverse-J pattern in New York Stock Exchange bid-ask spreads, they describe it as relatively crude.

Less research has been conducted on intraday patterns in commodities and other exchange traded asset classes. Eaves and Williams (2010), one of the few papers to analyse intraday patterns in a commodity markets, observe U-shaped intraday volume and L-shaped return volatility on the Tokyo Grain Exchange. Cyree and Winters (2001) find reverse-J intraday patterns in return variances and volume in the US Fed Funds market. Their results suggest this pattern is the result of trading stoppages rather than activity clustering around the transactions informed traders.

Foreign exchange markets trade continuously, and despite being an over-the-counter market, provide a close analogy in terms of trading hours to the markets we analyse in this paper. The full TOCOM trading day that we refer to as global trading hours includes the Tokyo day session plus the night session, and spans the normal working hours of Tokyo, London and much of New York. Most research on intraday patterns in currencies has focussed on return volatility and bid-ask spreads, for example, Bollerslev and Domowitz (1993) and Hsieh and Kleidon (1996). Ito and Hashimoto (2006) analyse intraday seasonality in quote revision frequency, trading volume, return volatility and bid-ask spreads for the USD/JPY and EUR/USD exchange markets over a 24 hour trading day, and describe intraday patterns during Tokyo, London and New York working hours. They find that quote revision frequency, trading volume and return volatility co-move, while spreads move in the opposite direction. Contrary to what is normally expected in equity markets, bid-ask spreads are low when volatility is high. Given that Tokyo hours overlap with London, and London hours overlap with New York, but New York hours do not overlap with Tokyo, U-shaped patterns in trading volume exist during Tokyo and London working hours, but not New York. There is no increase in activity at the end of New York working hours. Overlapping business hours appear to boost market activity and inter-regional transactions.

3.2.2 Relationships between microstructure characteristics

Researchers have also examined the intraday relationships between market microstructure characteristics. In particular, patterns of intraday informational efficiency may be correlated with intraday patterns in return volatility, trading volume and market liquidity. Theoretical explanations in the literature justify both positive and negative signs on these correlations based on whether transactions in the market are those of informed or uninformed traders. A variety of empirical evidence has been generated to support both interpretations.

Informational efficiency and return volatility may be related positively or negatively. The efficient markets hypothesis suggests that return volatility results when new information randomly hits the market. Volatility indicates the adjustment of prices to new information, and in that sense, is associated with informational efficiency. Alternatively, behaviouralists propose that volatility cannot be explained exclusively by changes in fundamentals. Noise traders transact irrationally, which leads to volatility in returns. Empirical studies suggest noise traders contribute to a substantial portion of volatility in asset price returns, for example, Shiller (1981), French and Roll (1986) and Schwert (1989). Informational efficiency and returns volatility should be negatively related if volatility resulting from the activities of noise traders dominates.

There are also two views regarding the relationship between volume and informational efficiency: the "asymmetric information view" and the "inventory control view". The asymmetric information view argues that trades are more informative when trading volume is high, while the inventory control view holds that trades are less informative when trading volume is high. Theory admits both possibilities, depending on the posited information structure.

To understand the asymmetric information view, consider the model of Admati and Pfleiderer (1988). To minimize their losses to informed traders, discretionary liquidity traders prefer to trade when they have little impact on prices. More liquidity trading in a given period encourages informed traders to transact at the same time as liquidity traders. Competition among informed traders reduces their total profit, benefiting liquidity traders and encouraging their further participation. An increase in the number of informed traders contributes to more informed prices because they cause prices to adjust faster to information. In this situation, trading volume and the informational efficiency of prices are positively related.

Alternatively, trading volume and efficiency may be negatively related. Uninformed traders adjust their positions from time to time. Market makers operate in commodity futures markets, and as part of their normal business activities, unavoidably take on positions they desire to shed immediately. The representative model of the inventory control view, developed by Lyons (1997), relies on hot potato trading – passing unwanted positions from dealer to dealer following an initial customer order, which reduces the informativeness of prices. Information aggregation by dealers occurs through signal extraction applied to order flow. The greater the noise relative to signal, the less effective signal extraction is. Passing hot potato trades increases the noise in order flow and dilutes informational content. Hence, trading volume and the informational efficiency of prices are negatively linked.

Theoretical arguments and empirical evidence also relate market liquidity with informational efficiency. Two views propose alternative signs for the relationship. The “transaction cost view” of liquidity can be described as the situation where greater market liquidity reduces transactions costs for informed traders, and their trades contribute to informational efficiency. Illiquid markets imply high transactions costs for informed traders and thus are less efficient. Kyle (1985) develops a model where an increase in liquidity leads informed traders to take more risk on existing information, and provides greater incentives for informed traders to gain more accurate information. Recent papers provide empirical support for the view that security mispricing is greater in illiquid markets (Sadka and Scherbina, 2007; Chordia et al., 2008). Payne (2003) demonstrates that in the USD/DEM market, high volume and liquidity periods are associated with relatively low price response, suggesting volume and liquidity are positively related to informational efficiency.

Alternatively, the “noise trader view” says that liquidity may be a proxy for uninformed trading and thus is associated with informational inefficiency. As a representative empirical paper to support this view, Tetlock (2007) uses data from short-horizon binary outcome securities traded in online exchanges to show that the most liquid securities markets exhibit significant pricing anomalies.

3.3 Data, Variables and Model

3.3.1 Data

We use 1-minute intraday bid and ask futures prices and trading volume for platinum and gold futures contracts. The Tokyo prices for both metals are from TOCOM, while the New York prices for platinum are from NYMEX and those for gold are from COMEX. The TOCOM data was purchased directly from the exchange. COMEX and NYMEX data was obtained from Thomson Reuters. The sample spans 128 trading days from 1 September 2014 to 31 March 2015[5]. We use the most traded contract on each exchange, which is the deferred contract for each metal on TOCOM and the nearby contract in New York. Transactions are denominated in Japanese yen on TOCOM, and in U.S. dollars on COMEX and NYMEX.

Our analysis is conducted based on the times of TOCOM's trading sessions. The TOCOM daytime trading session begins at 9:00 Japan Standard Time (JST) and ends at 15:15. After a break, the night session begins at 16:30 and ends at 4:00 the next morning[6]. We refer to the day plus the night session as global trading hours, which has a total of 1065 minutes of trading. Accordingly, we have 1065 one-minute price and volume observations for each

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[5] General financial market conditions during our sample period could be described as typical for markets following the global financial and European sovereign debt crises. Market volatility according to the Chicago Board Options Exchange VIX was elevated at times, but not extreme, due to news such as the Bank of Japan's surprise decision to extend its Qualitative and Quantitative Easing program, weak economic data from Europe and China, and the snap presidential election in Greece.

[6] TOCOM extended its trading hours on 20 September 2016, after the sample period for our study. The day session opens 15 minutes earlier at 08:45 JST, and closes at 15:15. The new night session is 90 minutes longer, and runs from 16:30 to 05:30 the next day (TOCOM, 2016).

trading day or set of global trading hours. We divide TOCOM's day and night session into nine non-overlapping time intervals denoted TI1 to TI9. TI1 to TI3 represent TOCOM's daytime trading session, and TI4 to TI9 represent TOCOM's night session. The daytime intervals are 125 minutes in duration, while the night intervals are 115 minutes long. Table 1 shows the JST, London (GMT) and New York (EST) times for each interval. We adjust for summer time as also shown in Table 3.1. We refer to TI1 to TI3 as the Tokyo day session, TI4 to TI6 as the London day session, and TI7 to TI9 as the New York day session. In total, our sample contains 1152 time intervals, comprising nine intervals per day for 128 trading days. We calculate observations for the variables discussed in the following section for each of the 1152 time intervals, and this is the data we use in our linear regression model and for our correlation analysis.

[Insert Table 3.1 here]

3.3.2 Variables

We are interested in comparing market efficiency, volatility, volume and liquidity characteristics and relationships between the markets in New York and Tokyo. Accordingly, we construct five relevant variables from our intraday price and volume data for each of the four futures contracts: TOCOM Platinum, NYMEX Platinum, TOCOM Gold and COMEX Gold. The five variables are Lo and MacKinlay's (1988) variance ratio (VR), realised volatility (RV), trading volume (Vol), quoted half-spread (Sp), and Amihud's (2002) measure of illiquidity (ILLIQ). The prices used in constructing the variance ratio, realised volatility, spread and illiquidity are in local currency terms. Fluctuation in the U.S. dollar / Japanese yen exchange rate means that the variance ratio and realised volatility of a metal will not be equal across exchanges. The variables are defined as follows.

Lo and MacKinlay (1988) use a ratio of variance estimators to provide evidence against random walks in stock price formation. They note that an important property of a random walk is that the variance of the increments of the random walk is a linear function of the observation interval of the increments. Returns that do not adhere to this property suggest that prices are not formed according to a random walk. The distance of Lo and MacKinlay's (1988) variance ratio from one indicates relatively greater informational inefficiency due to the existence of either positive or negative serial correlation in the returns.

We compute the variances of 1-minute and 5-minute continuously compounded (log) returns, r_t, for mid-quote prices as defined below in equations (3.1) and (3.2), respectively. The subscript t refers to time in minutes.

$$r_t = \ln p_t - \ln p_{t-1} \qquad (3.1)$$

$$r_t(5) = \ln p_t - \ln p_{t-5} \qquad (3.2)$$

We define our statistic as the absolute value of one minus the variance ratio, since we are interested in departures from a random walk in either direction, according to the formula in equation (3.3). The total number of minutes during each time interval, denoted as T, is equal to 125 and 115 minutes for the TOCOM day and night sessions, respectively. The term μ is defined as the mean one-minute return over the time interval. Equation (3.3) is interpreted as a measure of inefficiency.

$$VR = \left|1 - \frac{Var[r_t(5)]}{5*Var[r_t]}\right| = \left|1 - \frac{\frac{1}{T-5}\sum_{t=5}^{T}(r_t+\cdots+r_{t-4}-5\mu)^2}{\frac{5}{T-1}\sum_{t=1}^{T}(r_t-\mu)^2}\right| \qquad (3.3)$$

Realised volatility (RV) in each time interval is constructed using returns based on mid-quote prices to reduce spurious volatility due to bid-ask bounce. We multiply squared one-minute returns by 1065, representing the total number of minutes in global trading hours. Volatility is interpreted as daily percentage volatility during the time interval.

$$RV = 100 * \sqrt{\frac{1065}{T}\sum_{t=1}^{T} r_t^2} \qquad (3.4)$$

Trading volume (Vol) represents the average number of contracts traded per minute in each time interval. $Vol_t(unit)$ represents the number of contracts traded on the relevant exchange during each minute t of our sample.

$$Vol = \frac{1}{T}\sum_{t=1}^{T} Vol_t(unit) \qquad (3.5)$$

We gauge market liquidity using two different approaches. The quoted half-spread (Sp) is defined as follows.

$$Sp = \frac{1000}{2T}\sum_{t=1}^{T}\left(\frac{p_t^{ask}-p_t^{bid}}{(p_t^{ask}+p_t^{bid})/2}\right) \qquad (3.6)$$

In addition, we construct the measure of illiquidity (ILLIQ) suggested by Amihud (2002), and referred to as Amihud's ILLIQ. This measure can be thought of as quantifying the sensitivity of returns to trading volume. The more illiquid a market is, the greater is the impact of a particular level of trade volume on a security's return. It is calculated as an average for each time interval of the absolute value of 5-minute returns $r_t(5)_k$ divided by 5-minute trading volume by weight of metal in kilograms $Vol_t(5)(kg)$ for futures contract k. Using weight of metal in the denominator facilitates comparison between New York and Tokyo on an amount of metal basis. We use 5-minute returns, as quoted prices do not always change within each minute.

$$ILLIQ = 10^6 \times \frac{5}{T}\sum_{k=1}^{T/5}\frac{|r_t(5)_k|}{Vol_t(5)(kg)} \qquad (3.7)$$

3.3.3 Analysing intraday seasonality and microstructure relationships

We employ two approaches to analyse the intraday patterns and relationships between informational efficiency and volatility, volume and liquidity. Estimates from a linear regression model for each microstructure variable are used to characterise intraday seasonal patterns in each futures market, controlling for daily effects. We also examine Pearson correlation coefficients between the intraday informational efficiency and volatility, volume and liquidity variables for global trading hours as well as the Tokyo, London and New York day sessions.

We estimate the linear regression model represented by equation (3.8) for each of the five microstructure variables defined above: the variance ratio (VR), realized volatility (RV), trading volume (Vol), quoted half-spread spread (Sp), and Amihud's ILLIQ (ILLIQ).

$$y_{k,i,j} = \alpha_{k,1,1} + \sum_{i=2}^{9} \beta_{k,i} TI_i + \sum_{j=2}^{128} \gamma_{k,j} DD_j + \varepsilon_{k,i,j} \qquad (3.8)$$

One regression model is estimated for each microstructure variable and futures contract combination. The dependent variable $y_{k,i,j}$ is the variable of microstructure for futures contract k at time i, j, where i refers to the time interval and j to the day. We regress the dependent variable on an intercept $\alpha_{k,1,1}$, dummy variables for the time intervals TI_i for i equal to two to nine (TI2 to TI9), and daily dummy variables DD_j for each of the j days in our sample from day two to day 128.

The $\alpha_{k,1,1}$ and $\beta_{k,i}$ estimates are used to represent intraday seasonal patterns in the particular microstructure variable for contract k. The estimate for $\alpha_{k,1,1}$ represents the first time interval on the first trading day, and those for the $\beta_{k,i}$ represent the differential to $\alpha_{k,1,1}$ for each time interval of the day. The daily dummies are included to account for day effects, which control for to preclude large shocks from influencing intraday patterns and increasing correlations between variables. Our results do not change substantially if the daily dummies are omitted from the model. The model is estimated by ordinary least squares.

3.4 Empirical Results

3.4.1 Summary Statistics

Summary statistics for each variable are shown in Tables 3.2.1 and 3.2.2 for platinum and gold, respectively. Statistics for the variables related to contracts on TOCOM are denoted "TY", and those relating to contracts on the New York exchanges are denoted "NY". The mean and median variance ratio statistics for both platinum and gold are lower in New York than Tokyo, suggesting that the New York markets are more efficient on average. Realised volatility in Tokyo is on average lower than in New York for both metals, however the distribution of realised volatility for Tokyo is much more leptokurtic. Tokyo platinum mean and median trading volume exceeds those of New York in contract terms, and are substantially more variable. New York dwarfs Tokyo in trading volume for gold. The average of the bid-ask spread measures in the platinum markets are similar over the two exchanges, although Tokyo spreads appear tighter and less variable but with greater likelihood of extreme observations. The average spread on gold is much higher in Tokyo than in New York. For platinum, Amihud's ILLIQ tells a different story to the bid-ask spread, suggesting that the Tokyo market is notably less liquid than New York, since the measure normalises by trading volume in weight of metal. Both Amihud's ILLIQ and the spread suggest that gold market liquidity is substantially greater in New York than Tokyo.

[Insert Table 3.2.1 here]

[Insert Table 3.2.2 here]

3.4.2 Intraday Seasonality

Figures 3.2.1 to 3.2.5 show the intraday seasonal patterns for each microstructure variable and futures contract combination implied by the estimates from equation (3.8). The intraday seasonal pattern estimates are $\alpha_{k,1,1}$ for TI1 and the sum of $\alpha_{k,1,1}$ and the appropriate $\beta_{k,i}$ for TI2 to TI9. The left pane of each figure shows the estimates for platinum and the right pane shows those for gold. Tables A3.1.1 and A3.1.2 in the Appendix show the regression estimates, their statistical significance, and the adjusted coefficient of determination for each regression.

[Insert Table A3.1.1 here]

[Insert Table A3.1.2 here]

The estimates for the variance ratio models (see Figure 3.2.1) suggest that the first time interval of the day, TI1, is by far the least informationally efficient period of global trading hours in both the platinum and gold markets on both exchanges. Inefficiency peaks again in TI4 during the open of the London day session, albeit at a lower level than at the beginning of the Tokyo day. In contrast, the open of the New York day session (and immediately prior) is a relatively efficient time for both platinum and gold on both exchanges. The Tokyo and London day sessions are similar in that at the open the markets are relatively inefficient and are relatively more efficient later in their respective sessions. Conversely, the New York day session is different in that the market is relatively efficient at the open and is less efficient later in the session. Over global trading hours, the evolution of the variance ratio model estimates loosely resemble a W shape for each of the markets. Inefficiency rises at the end of the trading day in all of the markets, particularly in platinum on both the Tokyo and New York exchanges. While Tokyo appears marginally less efficient than New York in the platinum market over most of global trading hours, this differential between exchange efficiency is notably greater in the gold market, particularly after TI1.

[Insert Figure 3.2.1 here]

Figure 3.2.2 shows the estimates for the realised volatility models. These peak at the open of the Tokyo, London and New York day sessions for each market. Tokyo and New York open (TI1 and TI7, respectively) are the most volatile times. After the open, volatility during the Tokyo day is relatively low for both metals on both exchanges. Over global trading hours, volatility follows a U-shaped pattern over TI1 to TI4, and then rises into the New York open and then falls in an inverted U-shaped pattern from TI5 to TI9. During the Tokyo, London and New York day sessions, intraday volatility takes an L-shape in Tokyo hours, a U-shape in London hours, and declines in a linear fashion through New York hours. Patterns across the two metals are similar, while volatility is greater on the New York exchanges during most time intervals, and particularly during the New York day session.

[Insert Figure 3.2.2 here]

The intraday patterns indicated by the estimates from the trading volume models (see Figure 3.2.3) show greater differentiation across the four metal-exchange combinations than is the case for the variance ratio and realised volatility. In the markets for both metals, trading volume on each exchange is concentrated during that exchange's day session. Most platinum trade in Tokyo occurs soon after the open of the Tokyo trading day during the first time interval (TI1), when the market is at its least efficient and volatility is at its highest level. Platinum volume in Tokyo over the Tokyo day session is greater than the volume in Tokyo during either of the London or New York day sessions. Similarly, most platinum trade on the New York exchange occurs during the New York day session. Tokyo trading volume exceeds New York trading volume from TI1 to TI5, while the opposite is true from TI6 to TI9. During each of the Tokyo and London day sessions, TOCOM trading volume follows a reverse J-shaped pattern, but during the New York day session Tokyo trading volume falls off after peaking at the New York open. Gold trading volume in New York peaks at the New York open, and is at a relatively high level from TI6 to TI9. New York's trading volume in gold is far greater than Tokyo's, and trading volume in Tokyo fluctuates less over the nine time intervals.

[Insert Figure 3.2.3 here]

The estimates for the spread regressions, shown in Figure 3.2.4, broadly trend up over global trading hours (TI1 to TI9) for platinum and gold in Tokyo. Spreads on platinum in New York are at their lowest during the New York day, while New York gold spreads are relatively stable over the day. Estimates for the gold spread equations vary noticeably less than for platinum. Also in the platinum markets, the estimates for the spread models are clearly lower during each exchange's day session, and higher otherwise, which makes sense as spreads would be expected to be lower during higher trading volume periods. The estimates for TOCOM are lower during TI1 to TI3 and higher thereafter, while spreads are lower over TI7 to TI9 for the New York exchange. Consistent with the relative importance and relative trading volume of Tokyo and New York in the global gold market, the estimates for spread in Tokyo are much larger than (about double) those for New York. In contrast, platinum spread model estimates for Tokyo are lower than those on New York during the Tokyo day session, while this situation reverses during the New York day session. During the London day session, platinum spread estimates for the Tokyo and New York exchanges are about the same.

[Insert Figure 3.2.4 here]

Our estimates for the ILLIQ models are shown in Figure 3.2.5 and display more intraday variation, telling a more interesting story about intraday liquidity than the estimates from the spread models. The ILLIQ estimates show that each exchange is more liquid during its own day session. While the Tokyo platinum market is more liquid than New York during the Tokyo day, from TI5 onward New York is the more liquid market. In contrast, the Tokyo and New York gold markets start global trading hours at about the same level of liquidity, after which the Tokyo market becomes more illiquid while the New York market becomes more liquid.

[Insert Figure 3.2.5 here]

3.4.3 Relationships between microstructure characteristics

Table 3.3.1 and 3.3.2 show the correlations between the variance ratio variable and each of return volatility, trading volume, spread and ILLIQ, for platinum and gold, respectively. We reverse the signs of the correlations between the variance ratio and both realised volatility and trading volume. Accordingly, the results can be read more intuitively as the correlations between informational efficiency and volatility, and efficiency and volume. No such transformation is required to interpret the remaining correlations as being between efficiency and liquidity. The first two columns of Tables 3.1 and 3.2 refer to correlations between the variables over global trading hours (TI1 to TI9). These correlations are calculated over 1152 time interval observations. The subsequent three pairs of columns to the right reflect the Tokyo day session (TI1 to TI3), the London day session (TI4 to TI6) and the New York day session (TI7 to TI9), which are calculated over 384 time intervals. Correlations in bold are significant at the 10 percent level or less.

[Insert Table 3.3.1 here]
[Insert Table 3.3.2 here]

All global trading hours correlations for the Tokyo exchange are negative in both the platinum and gold markets, and all except the correlation between efficiency and volume for gold are significant. This suggests that over global trading hours, the gold and platinum markets on TOCOM are dominated by uninformed traders. New York platinum and gold market correlations for global trading hours provide evidence for both informed and uninformed trading. Efficiency is negatively correlated with volatility suggesting the transactions of uninformed traders, likely those with little discretion over when they trade, give rise to volatility. However, efficiency is positively correlated with volume, as hypothesised under Admati and Pfleiderer’s (1988) asymmetric information view where informed and discretionary uninformed traders prefer to trade together such that they have low market impact. The correlations between efficiency and the two liquidity measures are not significant.

We find a more nuanced view of the intraday relationships between efficiency and volatility, volume and liquidity in the correlations for the Tokyo, London and New York day sessions. Consistent with anecdotal evidence from market participants that firms with large physical platinum exposures enter the market during the Tokyo morning to hedge via TOCOM, the correlations for both the Tokyo and New York platinum markets support uninformed trader interpretations during the Tokyo day. Efficiency is significantly negatively correlated with volatility, volume and the two liquidity measures for platinum traded on TOCOM. Similarly, all correlations are negative for platinum traded in New York during the Tokyo day. All except the correlation between efficiency and liquidity (spread) are significant. Efficiency is also negatively and significantly correlated with volatility for gold in both Tokyo and New York, with volume in New York only, and with ILLIQ in Tokyo only. While there is support for uninformed trading in both metals during the Tokyo day, the evidence for platinum is stronger than that for gold.

During the London day session, the correlations are less definitive. The correlation between efficiency and liquidity (ILLIQ) supports a noise trader view for the TOCOM platinum market. However, in the New York platinum market the correlations with volume and liquidity (ILLIQ) are both positive and significant, supporting the asymmetric information view and the transactions cost view, respectively. The correlation with volatility is negative and significant, suggesting uninformed trading. For the gold markets, negative correlations between efficiency and liquidity (ILLIQ) in Tokyo, and efficiency and volatility in New York, provide some support for uninformed trading during the London day session.

Our results for the New York day session support the dominance of informed trading for both metals traded on both exchanges. The evidence is stronger for gold than platinum in terms of the size of the correlations for both trade in Tokyo and New York, and in terms of the number of significant correlations for Tokyo. Correlations between efficiency and volatility are positive and significant over all four markets, and those between efficiency and volume are positive and significant for platinum and gold in New York, and gold but not platinum in Tokyo. These correlations suggest that uninformed traders are likely absent from the Tokyo market during the Tokyo night session when volume and liquidity are low. This concurs with anecdotal evidence that large hedgers of physical platinum enter the market primarily during the Tokyo morning. Informed traders appear to trade in Tokyo at night while overlapping with the New York day, despite the relatively low liquidity compared with the Tokyo day session. They are likely arbitraging between the two markets during the New York day.

The evidence from the correlation analysis is consistent with the patterns evident in the charts of the regression estimates. Relatively high variance ratio (Figure 3.2.1) and realised volatility (Figure 3.2.2) model estimates occur in TI1 and TI4. This implies informational efficiency is negatively related to volatility, implying that volatility is the result of the market transactions of uninformed traders. From around the New York open (TI7) low variance ratio model estimates are associated with high realised volatility estimates, consistent with the rational adjustment of prices to new information. Taken together, Figures 3.2.1 and 3.2.3 suggest efficiency is negatively related to trading volume during the Tokyo day, particularly for platinum on TOCOM. TI1 is the busiest trading time for platinum on TOCOM, and also the least efficient time. By the New York day session, the regression model estimates suggest a positive relationship between efficiency and volume for both metals on both exchanges. The spread model estimates (Figure 3.2.4) do not show a great deal of intraday variation, and accordingly their relationship with efficiency is less clear than for the preceding variables. However, it would appear that efficiency and liquidity are negatively related, at least for platinum and gold on TOCOM over global trading hours, suggesting liquidity is a proxy for uninformed trading. Similarly, the variance ratio and ILLIQ (Figure 3.2.5) estimates broadly suggest a negative relationship between efficiency and liquidity in the Tokyo markets and a positive relationship in New York over global trading hours.

3.5 Conclusion

This chapter examines the intraday seasonality of informational efficiency, return volatility, trading volume and market liquidity in the platinum and gold futures markets on exchanges in Tokyo and New York using high frequency 1-minute data covering global trading hours from September 2014 to March 2015. Platinum and gold provide an interesting comparison as Tokyo is an internationally important center for platinum trading but not for gold. We also examine the relationships between market microstructure characteristics to determine whether trading in these markets is predominantly informed or liquidity driven. The article aims to contribute to the understanding of commodity futures market microstructure, on which there has been little research to date.

We find the following regularities in intraday market characteristics. Informational inefficiency in both the platinum and gold markets conforms to a W-shape over global trading hours. The Tokyo and London open, and later in the New York day, show the highest levels of inefficiency. Day sessions in Tokyo and London start relatively inefficient and become more efficient. In the New York day session, the markets start relatively efficient and become inefficient by late in its session. Volatility also follows a similar pattern for both metals and exchanges. It is relatively high at the open of the Tokyo, London and New York day sessions, being L-shaped in Tokyo hours, U-shaped in London hours, and declining approximately linearly in New York hours. In contrast, intraday volume and liquidity patterns differ between the metals and/or exchanges. Trading volume in platinum is concentrated on each of the Tokyo and New York exchanges during their day sessions, while comparatively more platinum volume on TOCOM occurs through the New York day than NYMEX volume through the Tokyo day. Tokyo platinum volume shows reasonably clear reverse-J and L-shaped patterns during the Tokyo and London day sessions, respectively. Volume in all the markets declines monotonically during the New York day session. In the gold market, volume builds to a peak at the New York open on COMEX that dwarfs the volume on TOCOM. Liquidity on each exchange is greatest during that exchange's day session, and Amihud's ILLIQ shows Tokyo liquidity deteriorating over global trading hours.

Relationships uncovered between informational efficiency and volatility, volume and liquidity suggest that over global trading hours both the platinum and gold markets in Tokyo are dominated by uninformed trading, while there is evidence supporting both uninformed and informed trading in New York. During the Tokyo day session, uninformed traders dominate the platinum and gold markets in both Tokyo and New York. Conversely, during the New York day session, informed traders dominate.

Arbitrage means the intraday patterns of return related market characteristics, such as efficiency and volatility, remain closely related across exchanges trading the same commodity. However, market activity measures such as volume and liquidity can differ substantially between the exchanges over the course of global trading hours. The Tokyo and New York exchanges examined in this research have overlapping trading sessions. Night sessions supplement the exchanges' daytime trading hours. This overlap of trading influences intraday microstructure patterns on each exchange over global trading hours, and the absence of an overlap between day trading sessions at the end of global trading hours also influences microstructure patterns. The resulting intraday patterns share similarities with the intraday patterns seen in the continuously traded foreign exchange markets, as identified by Ito and Hashimoto (2006). Market participants in different time zones and different geographical locations have different motivations for trading. Uninformed trading is prevalent during the Tokyo day session when most volume goes through Tokyo markets. While during New York hours, informed trading dominates during the New York exchanges' busiest times. This evidence suggests that futures markets for the same underlying commodity on different exchanges have different microstructure characteristics, while both informed and uninformed traders choose when to trade depending on market characteristics in different time zones.

Figure 3.1: Monthly Contract Volume

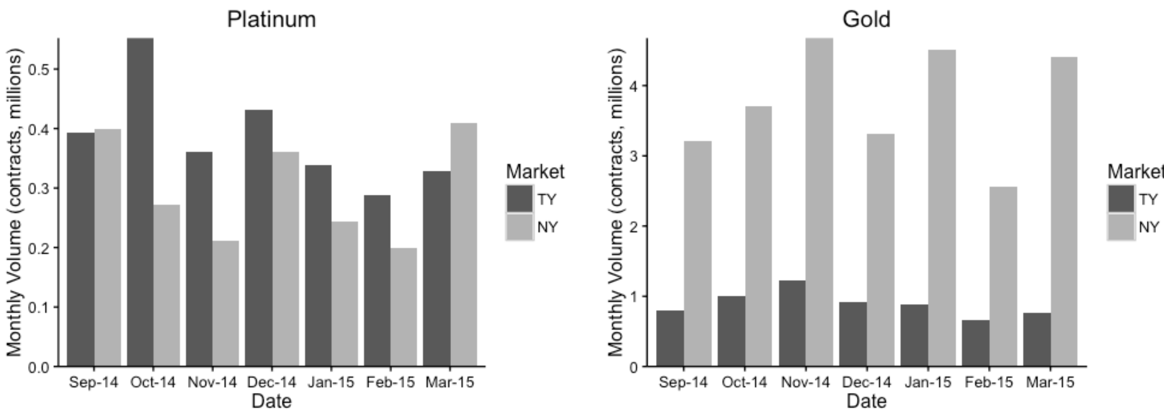


Figure 3.2.1: Variance Ratio

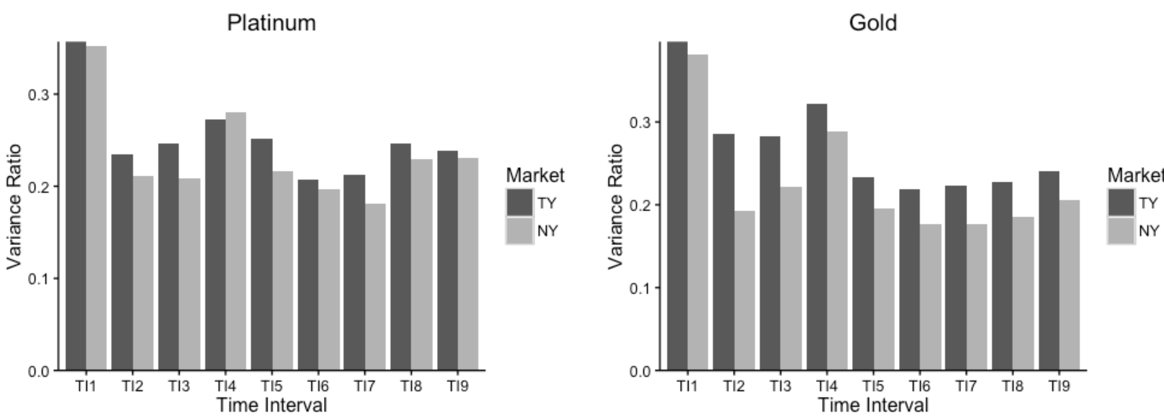


Figure 3.2.2: Realised Volatility

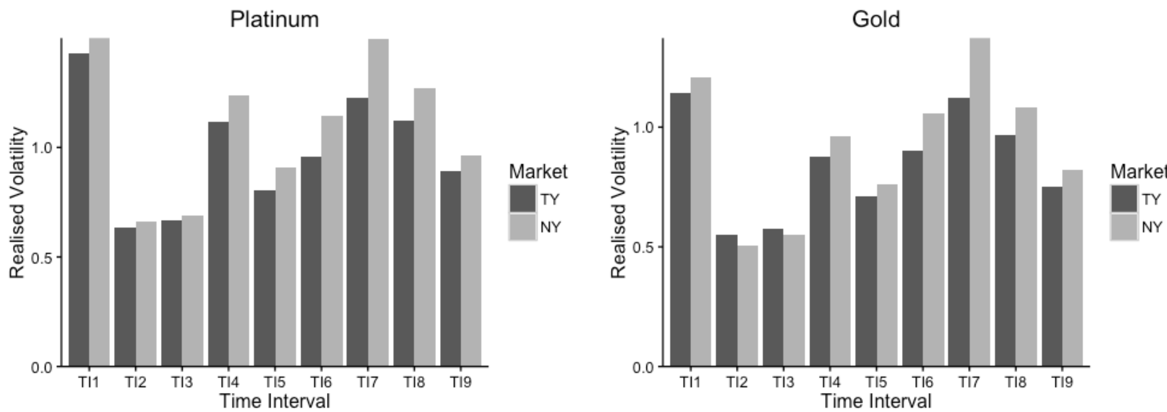


Figure 3.2.3: Trading Volume

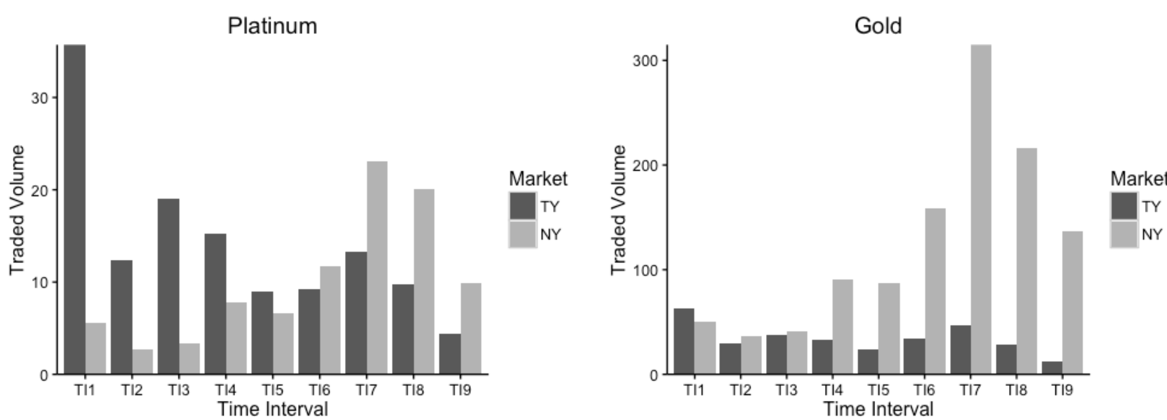


Figure 3.2.4: Spread

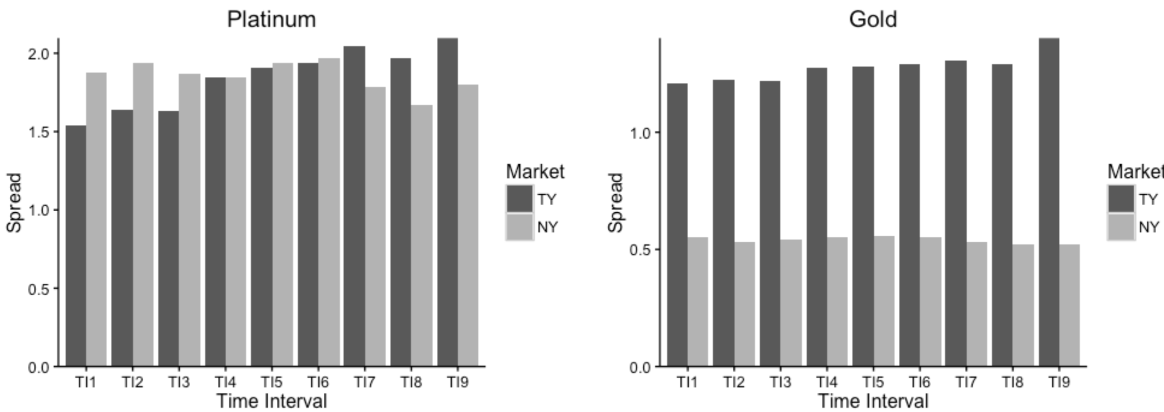


Figure 3.2.5: Illiquidity

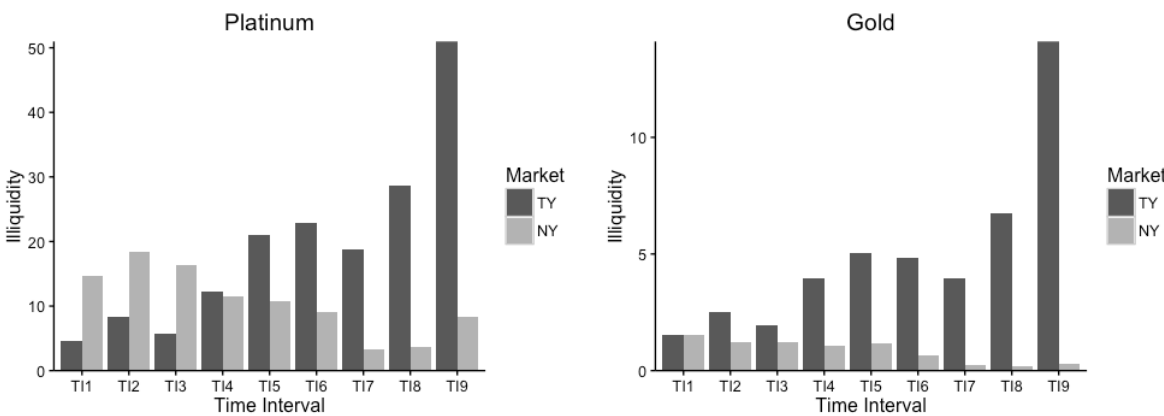


Table 3.1: Time Intervals

Time Interval	Duration (minutes)	Session Described As	Tokyo (JST)		London (GMT)		London (DST) (London Summer)		New York (EST)		New York (DST) (New York Summer)	
			Start Time	End Time	Start Time	End Time	Start Time	End Time	Start Time	End Time	Start Time	End Time
TI1	125	Tokyo Day	09:00:00	11:04:59	0:00:00	02:04:59	01:00:00	03:04:59	-19:00:00	-21:04:59	-20:00:00	-22:04:59
TI2	125	Tokyo Day	11:05:00	13:09:29	02:05:00	04:09:59	03:05:00	05:09:59	-21:05:00	-23:09:59	-22:05:00	00:09:59
TI3	125	Tokyo Day	13:10:00	15:14:59	04:10:00	06:14:59	05:10:00	07:14:59	-23:10:00	01:14:59	00:10:00	02:14:59
TI4	115	London Day	16:30:00	18:24:59	07:30:00	09:24:59	08:30:00	10:24:59	02:30:00	04:24:59	03:30:00	05:24:59
TI5	115	London Day	18:25:00	20:19:59	09:25:00	11:19:59	10:25:00	12:19:59	04:25:00	06:19:59	05:25:00	07:19:59
TI6	115	London Day	20:20:00	22:14:59	11:20:00	13:14:59	12:20:00	14:14:59	06:20:00	08:14:59	07:20:00	09:14:59
TI7	115	New York Day	22:15:00	+00:09:59	13:15:00	15:09:59	14:15:00	16:09:59	08:15:00	10:09:59	09:15:00	11:09:59
TI8	115	New York Day	+00:10:00	+02:04:59	15:10:00	17:04:59	16:10:00	18:04:59	10:10:00	12:04:59	11:10:00	13:04:59
TI9	115	New York Day	+02:05:00	+03:59:59	17:05:00	18:59:59	18:05:00	19:59:59	12:05:00	13:59:59	13:05:00	14:59:59

Table 3.2.1: Summary Statistics for Platinum

Statistic	Variance Ratio TY	Variance Ratio NY	Realised Volatility TY	Realised Volatility NY	Trading Volume TY	Trading Volume NY	Spread TY	Spread NY	Illiquidity TY	Illiquidity NY
Mean	0.252	0.234	0.983	1.096	14.223	10.127	1.841	1.854	19.142	10.654
Median	0.239	0.209	0.872	0.976	10.400	6.625	1.875	1.802	12.613	8.603
Minimum	0.000	0.000	0.245	0.233	0.287	0.528	1.077	0.900	0.858	0.833
Maximum	0.965	0.932	9.823	9.152	131.040	60.278	3.447	3.890	180.336	52.357
Standard Deviation	0.170	0.165	0.628	0.656	13.082	9.471	0.261	0.416	20.105	7.855
Skewness	0.644	0.842	6.412	4.685	2.939	1.741	0.109	0.729	2.914	1.255
Kurtosis	0.159	0.567	73.100	44.166	13.860	3.469	3.208	0.830	12.853	1.725
Observations	1152	1152	1152	1152	1152	1152	1152	1152	1152	1152

Table 3.2.2: Summary Statistics for Gold

Statistic	Variance Ratio TY	Variance Ratio NY	Realised Volatility TY	Realised Volatility NY	Trading Volume TY	Trading Volume NY	Spread TY	Spread NY	Illiquidity TY	Illiquidity NY
Mean	0.270	0.225	0.845	0.924	34.456	125.895	1.277	0.539	4.958	0.843
Median	0.256	0.193	0.716	0.781	26.756	81.239	1.268	0.532	3.377	0.366
Minimum	0.000	0.000	0.229	0.192	1.826	0.328	1.082	0.442	0.544	0.074
Maximum	0.879	0.907	12.630	11.587	219.360	807.609	1.755	1.286	63.842	56.556
Standard Deviation	0.177	0.169	0.613	0.652	27.120	121.566	0.086	0.076	5.587	3.901
Skewness	0.568	1.042	9.136	5.913	2.190	2.024	1.200	4.170	4.231	8.833
Kurtosis	-0.152	0.960	146.010	72.775	7.169	5.044	3.590	29.249	26.006	10.394
Observations	1152	1152	1152	1152	1152	1152	1152	1152	1152	1152

Table 3.3.1: Correlations between Efficiency and Volume, Volatility and Liquidity for Platinum

	All Sessions (Global Trading Hours)		Tokyo Day Session		London Day Session		New York Day Session	
Correlation of Efficiency with	Tokyo	New York	Tokyo	New York	Tokyo	New York	Tokyo	New York
Volatility (Realised Volatility)	-0.151 ***	-0.219 ***	-0.370 ***	-0.486 ***	-0.004	-0.087 *	0.113 **	0.091 *
Volume (Trading Volume)	-0.144 ***	0.098 ***	-0.223 ***	-0.174 ***	0.007	0.100 **	0.059	0.099 *
Liquidity (Spread)	-0.127 ***	-0.019	-0.120 **	-0.029	-0.056	-0.030	-0.013	-0.047
Liquidity (Illiquidity)	-0.087 ***	0.031	-0.144 ***	-0.187 ***	-0.129 **	0.090 *	0.022	0.081

Note: ***, **, and * denote significance of the Pearson correlation coefficient at the 1, 5 and 10 percent levels, respectively.

Table 3.3.2: Correlations between Efficiency and Volume, Volatility and Liquidity for Gold

	All Sessions (Global Trading Hours)		Tokyo Day Session		London Day Session		New York Day Session	
Correlation of Efficiency with	Tokyo	New York	Tokyo	New York	Tokyo	New York	Tokyo	New York
Volatility (Realised Volatility)	-0.104 ***	-0.222 ***	-0.302 ***	-0.503 ***	-0.078	-0.170 ***	0.209 ***	0.156 ***
Volume (Trading Volume)	-0.041	0.150 ***	-0.069	-0.133 ***	0.019	0.028	0.118 **	0.163 ***
Liquidity (Spread)	-0.123 ***	0.026	0.062	0.065	-0.012	-0.031	-0.051	-0.016
Liquidity (Illiquidity)	-0.116 ***	0.037	-0.108 **	0.059	-0.115 **	-0.024	0.013	-0.009

Note: ***, **, and * denote significance of the Pearson correlation coefficient at the 1, 5 and 10 percent levels, respectively.

Appendix

Table A3.1.1: Estimates for Platinum

Variable	Constant	TI2	TI3	TI4	TI5	TI6	TI7	TI8	TI9	Adjusted R^2
Variance Ratio TY	0.357 ***	-0.122 ***	-0.111 ***	-0.084 ***	-0.106 ***	-0.150 ***	-0.145 ***	-0.110 ***	-0.118 ***	0.053
Variance Ratio NY	0.352 ***	-0.141 ***	-0.143 ***	-0.072 ***	-0.136 ***	-0.155 ***	-0.171 ***	-0.123 ***	-0.121 ***	0.083
Realised Volatility TY	1.430 ***	-0.796 ***	-0.761 ***	-0.313 ***	-0.626 ***	-0.471 ***	-0.206 ***	-0.310 ***	-0.519 ***	0.151
Realised Volatility NY	1.499 ***	-0.837 ***	-0.808 ***	-0.263 ***	-0.591 ***	-0.354 ***	-0.002	-0.230 ***	-0.537 ***	0.196
Trading Volume TY	35.717 ***	-23.321 ***	-16.639 ***	-20.457 ***	-26.708 ***	-26.488 ***	-22.494 ***	-25.967 ***	-31.370 ***	0.425
Trading Volume NY	5.558 ***	-2.818 ***	-2.144 **	2.300 ***	1.067	6.199 ***	17.579 ***	14.574 ***	4.360 ***	0.505
Spread TY	1.540 ***	0.097 ***	0.089 ***	0.309 ***	0.369 ***	0.399 ***	0.467 ***	0.428 ***	0.557 ***	0.489
Spread NY	1.874 ***	0.067	-0.004	-0.030	0.064	0.096 *	-0.086 *	-0.207 ***	-0.074	0.039
Illiquidity TY	4.647 ***	3.766 **	1.106	7.560 ***	15.287 ***	18.280 ***	14.129 ***	23.996 ***	46.335 ***	0.456
Illiquidity NY	14.749 ***	3.627 ***	1.529 **	-3.323 ***	-3.944 ***	-5.746 ***	-11.411 ***	-11.087 ***	-6.501 ***	0.391

Note: ***, **, and * denote significance of the coefficient at the 1, 5 and 10 percent levels, respectively.

Table A3.1.2: Estimates for Gold

Variable	Constant	TI2	TI3	TI4	TI5	TI6	TI7	TI8	TI9	Adjusted R^2
Variance Ratio TY	0.397 ***	-0.111 ***	-0.115 ***	-0.075 ***	-0.164 ***	-0.178 ***	-0.174 ***	-0.170 ***	-0.156 ***	0.093
Variance Ratio NY	0.381 ***	-0.188 ***	-0.160 ***	-0.092 ***	-0.186 ***	-0.205 ***	-0.205 ***	-0.195 ***	-0.175 ***	0.139
Realised Volatility TY	1.142 ***	-0.590 ***	-0.568 ***	-0.267 ***	-0.433 ***	-0.241 ***	-0.018	-0.173 **	-0.389 ***	0.104
Realised Volatility NY	1.210 ***	-0.707 ***	-0.660 ***	-0.247 ***	-0.447 ***	-0.152 **	0.162 **	-0.127 *	-0.391 ***	0.172
Trading Volume TY	63.094 ***	-33.170 ***	-24.951 ***	-30.503 ***	-39.068 ***	-29.068 ***	-15.764 ***	-34.962 ***	-50.256 ***	0.243
Trading Volume NY	50.712 ***	-13.753	-9.232	39.694 ***	35.948 ***	107.688 ***	264.237 ***	166.044 ***	86.021 ***	0.513
Spread TY	1.207 ***	0.018 **	0.010	0.069 ***	0.071 ***	0.084 ***	0.099 ***	0.085 ***	0.195 ***	0.421
Spread NY	0.550 ***	-0.018 *	-0.009	0.000	0.005	0.002	-0.016 *	-0.028 ***	-0.028 ***	0.019
Illiquidity TY	1.529 ***	0.989 *	0.429	2.429 ***	3.488 ***	3.305 ***	2.421 ***	5.219 ***	12.584 ***	0.408
Illiquidity NY	1.513 ***	-0.298	-0.294	-0.471	-0.361	-0.838 *	-1.256 ***	-1.316 ***	-1.196 **	0.007

Note: ***, **, and * denote significance of the coefficient at the 1, 5 and 10 percent levels, respectively.

Chapter 4. Intraday relationships between Arbitrage, Liquidity and Price discovery : Platinum Futures in Tokyo and New York

4.1 Introduction

Liquidity has long been thought to influence participants ability to arbitrage in financial markets. Recently, researchers have examined how arbitrage effects market liquidity. Deviations from no-arbitrage relations should be related to market liquidity, because liquidity facilitates arbitrage (Roll, Schwartz, and Subrahmanyam, 2007). Arbitrage opportunities due to demand shocks are liquidity enhancing (Holden, 1995; Gromb and Vayanos, 2010). The idea is that if arbitrage opportunities arise as a result of demand pressure, arbitrageurs trade against market demand and thereby decrease inventory holding costs for liquidity providers, which improves liquidity. Arbitragers trade against prevailing market demand to provide liquidity to other market participants in exchange for a premium, and improve market integration (Rosch, 2014). Alternatively, arbitrage opportunities due to information asymmetry between market participants reduce liquidity (Seppi and Kumar, 1994; Foucault et al., 2016). In this case, dealers widen bid-ask spreads and adverse selection cost on days when the fraction of toxic arbitrage opportunities and arbitrageurs' relative speed are higher, to slow their trading and compensate the risk of trading at stale quotes (Foucault et al., 2016).

There have been many insightful previous studies of the relation between liquidity and arbitrage in multiple stock markets. Roll, Schwartz, and Subrahmanyam (2007) study dynamic relation between stock market liquidity and the index futures basis, there is evidence of two-way Granger causality between the short-term absolute basis and liquidity, as measured by effective spread; shocks to spreads are more informative in forecasting shifts in the longer-term absolute basis than in the shorter-term bases, suggesting that liquidity affects arbitrageurs the relatively less actively traded longer-term. Rosch (2014) study the impact of arbitrage in Depositary Receipts (DRs) on market liquidity, using tick-by-tick data from the U.S. and five different home markets from 1996 to 2013, the results is more than half of Opportunity-Profit Granger causes home- and host-market quoted spread, and most arbitrage opportunities in DRs arise as a result of demand shocks, indicating that an increase in arbitrage activity predicts an increase in liquidity. Foucault et al. (2016) provide supporting evidence that the price efficiency gain of high-frequency arbitrage comes at the cost of increased adverse selection risk, using arbitrage opportunities and illiquidity measures be the observed exogenous variables.

Liquidity and price discovery are also related. Price discovery may shift from one market to another over time for several reasons, one of them being liquidity. Considering two markets for the same security, the more liquid market is expected to be more important in price discovery. A liquid market attracts liquidity traders and more informed traders, that trading will become more concentrated (Admati and Plfeiderer, 1988), because such market is “thick”, which liquidity traders’ trading has little effects on prices and informed traders can exploit their private information without making large price concessions. At the same time, liquid markets may attract more analysts, which further improves the informational environment. Overall, an increase in liquidity could thus lead to an improvement in price discovery for that market. But improvement in price discovery lead to more market liquidity is not known.

One type of liquidity, which is important for price discovery, is trading volume. It is often observed that large trades have persistent price impact, with trade prices lower after large sales and higher after large purchases. Traders interpret high volume as an indication that the demand underlying a price change is informative, and therefore should get incorporated into prices. Hasbrouck (1995) finds a positive and statistically significant correlation between the NYSE contribution to price discovery and its market share by trading volume for a sample of 30 Dow stocks. He explains that markets differ in their ability to process information such as that coming from trades. A market with an informative trading process can shed light on the interpretation of public information, and therefore, leads in terms of price discovery.

Another important determinant of price discovery is the relative bid-ask spread. The trading cost hypothesis predicts that the market with the lower trading costs will react more quickly to new information, as information-based trades are executed where they produce the highest net profit. As a result, lower relative bid-ask spreads and higher relative trading activity increase an exchange's contribution to price discovery. Harris et al. (2002) relate changes in price discovery to changes in the relative transaction costs between the NYSE and regional exchanges in the US at three discrete points in time. They conclude that higher NYSE spreads reduce the NYSE share of price discovery. Eun and Sabherwal (2003) examine the contribution of cross-listings to price discovery for a sample of Canadian stocks listed on both the TSE (Toronto Stock Exchange) and a U.S. exchange They find that while both the U.S. exchange and TSE contribute to price discovery, for most stocks, the U.S. prices adjust more to TSE prices than vice versa. Using cross-sectional regressions to analyze the determinants of price discovery, they find the U.S. share is inversely related to the ratio bid-ask spreads, but also find positive relations with the U.S. share of trading and to the ratio of proportions of informative trades on the U.S. exchange and the TSE. Foucault et al. In addition, Chakravarty et al. (2004) investigate the contribution of option markets to price discovery, using 5 years of transactions data for 60 stocks that are listed on the NYSE and that have options trading on the CBOE (Chicago Board Options Exchange), they find evidence of significant price discovery in the options market to be about 17% on average, and Option markets tend to be more informative on average when option trading volume is high, when option effective spreads are narrow, and when underlying volatility is higher.

Not only most previous studies that considered arbitrage and liquidity measures as the exogenous determinants to each other to investigate the relation (Roll, Schwartz, and Subrahmanyam, 2007; Rosch, 2014; Foucault et al., 2016), but also few studies that investigate the drivers and determinants of price discovery (Harris et al. 2002; Eun and Sabherwal, 2003; Chakravarty et al., 2004), they do not address the potential endogeneity issue. An important issue in this chapter is the presence of endogeneity, where causality may run from either arbitrage and price discovery to measures of market liquidity, or the other way around. To resolve this endogeneity problem, we employ a SEM (simultaneous equation model) to demonstrate that there is indeed a potential endogenous relation between the various measures of market liquidity and arbitrage, and liquidity and price discovery.

The platinum futures markets in Tokyo and New York trade securities based on the same underlying commodity, however, their intraday liquidity patterns are distinct. Liquidity on each market is greatest during the exchanges day time trading session. We model intraday arbitrage opportunities across Tokyo and New York, defined as deviations from the law of one price, as a function of liquidity of the markets, and liquidity as a function of arbitrage opportunities, with the aim of identifying a relationship. We also seek to establish whether the more liquid market at a given time during the day has greater impact on price discovery. The platinum markets in Tokyo on the Tokyo Commodity Exchange (TOCOM) and the New York Mercantile Exchange (NYMEX) provide a good setting to test arbitrage liquidity and liquidity price discovery interactions. Both markets trade futures based on the same underlying commodity, and the securities can be considered equivalent after taking account of contract specification differences and exchange rates. Both markets are considered internationally important venues for platinum trade, and participants include the major speculators and hedgers.

Historically, TOCOM has been an important global venue for trading platinum futures. In the past, activity in the global market for platinum has been heavily influenced by the hedging trades of large industrial end consumers of platinum metal in Japan who access the futures market via TOCOM. Until recently, the total weight of platinum represented by futures traded on TOCOM far outweighed that of NYMEX. In 2008 for example, 3.5 million kilograms was traded on TOCOM, or 4.4 times that of NYMEX. However, annual volume on the Tokyo market has been in long-term decline, down from over 16 million contracts in 2001 to just over 3.1 million contracts in 2016 (including both the platinum standard and mini contracts). In 2015 NYMEX was about 2.9 times larger than Tokyo by weight of platinum, and 4.2 times larger in 2016. However, in terms of contract volume, monthly turnover in Tokyo usually exceeds that of New York. Despite the decline in TOCOM volume, a not insubstantial share of the global platinum futures trade still occurs on the exchange and important end users of physical platinum continue to use TOCOM futures for hedging. Both exchanges operate extended hours such that their full day trading sessions overlap. An important difference between the Tokyo and New York futures markets for both platinum and gold is the most actively traded maturity. In New York, as with most commodity futures markets, nearby contract months are the most actively traded, while deferred contract months tend to be inactively traded. As noted in Kang et al. (2011), platinum and gold in Tokyo are actively traded in deferred contract months and inactively traded in nearby contract months.

We examine intraday relationships between liquidity and arbitrage, and liquidity and price discovery in the markets for platinum futures in Tokyo and New York, and find that an improvement in arbitrage activity reduces the Opportunity-Profit between Tokyo and New York, while Opportunity-Profit and liquidity difference are positively related, which provides support for the view that arbitrageurs tend to trade against market order imbalance and thus enhance market integration and liquidity; liquidity is also related to price discovery, a decrease in illiquidity (Spread and Zero-volume measure)and an increase in liquidity (Amivest measure and Volume) in one market relative to another increase the contribution of that market to price discovery, which implies that the market which provides better liquidity will become more important in terms of price discovery.

The chapter proceeds as follows. In the next section, In section 2, we describe our platinum data, variables for arbitrage, liquidity and price discovery, and the regression model. In section 3, we present and discuss our empirical results, and section 4 concludes.

4.2 Data, Variables and Model

We use 1-minute data for platinum futures contracts of the same maturity traded on TOCOM and NYMEX, consisting of bid and ask prices and trading volumes. The far contract as of May 2015 is used. Our data set covers all trading days from May 2015 to April 2016, giving a sample of 223,650 observations. We also use 1-minute USD/JPY foreign exchange rate data. All data are obtained from Bloomberg and Reuters. We use these data to construct the arbitrage profit, price discovery, and liquidity measures explained below.

Our analysis is conducted based on the times of TOCOM's trading sessions. The TOCOM daytime trading session begins at 9:00 Japan Standard Time (JST) and ends at 15:15. After a break, the night session begins at 16:30 and ends at 4:00 the next morning. We refer to the day plus the night session as global trading hours, which has a total of 1,065 minutes of trading. Accordingly, we have 1065 one-minute price and volume observations for each trading day or set of global trading hours. We divide TOCOM's day and night session into three non-overlapping time intervals denoted Tokyo, London and New York day session, and London and New York Day session represent TOCOM's night session. The daytime intervals are 375 minutes in duration, while the night intervals are 345 minutes long. In total, our sample contains 630 time intervals, comprising three intervals per day for 210 trading days. We calculate observations for the variables discussed in the following section for each of the 630 time intervals, and this is the data we use in our linear regression model and for our correlation analysis.

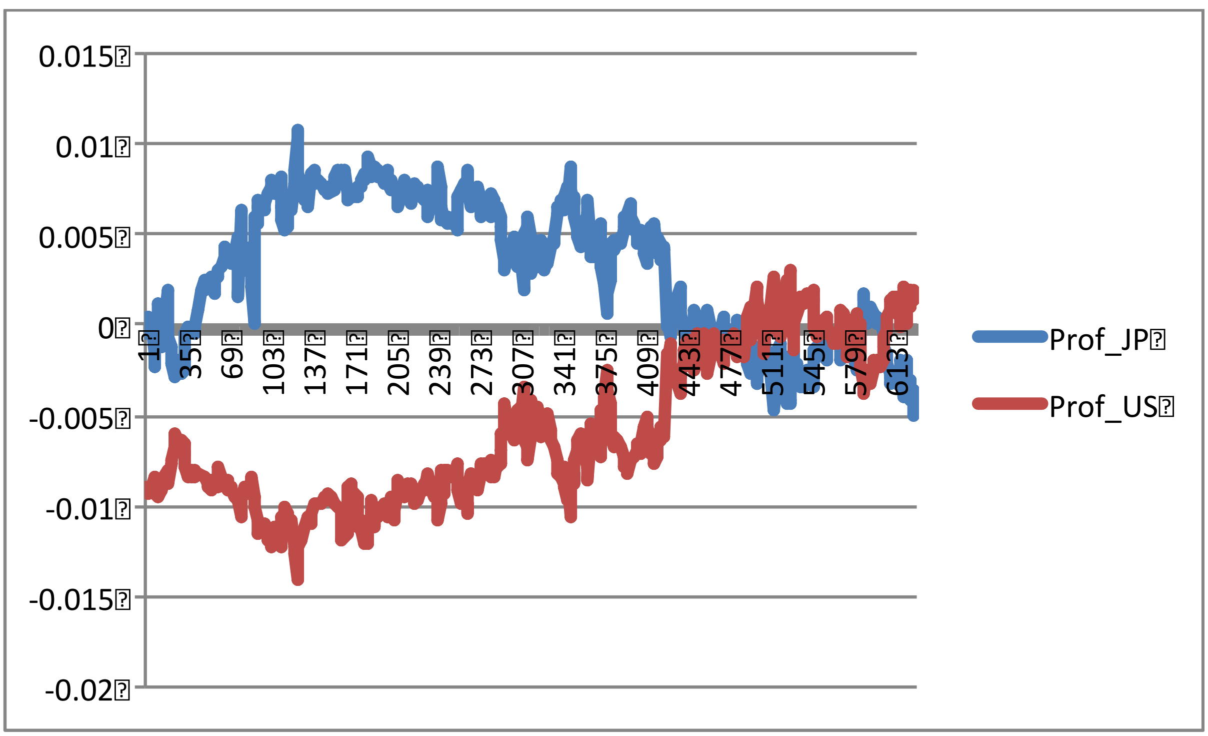
4.2.1 Arbitrage Profit Measures

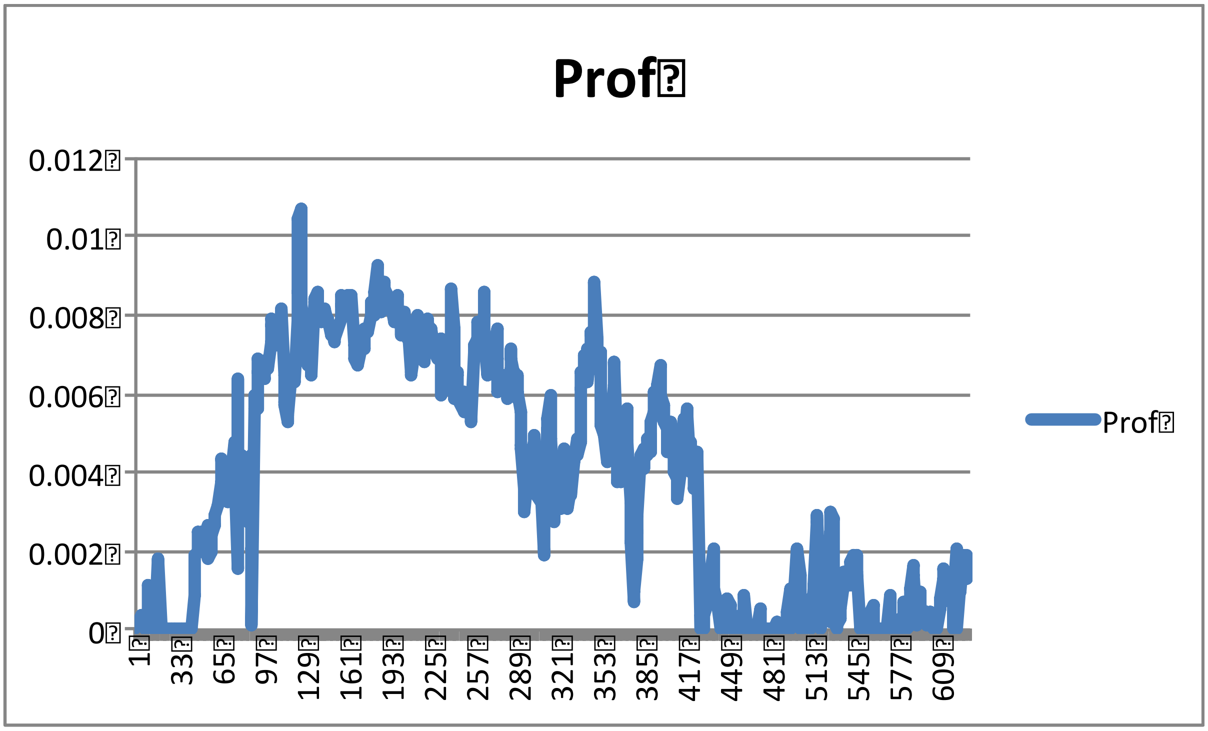
We construct the price deviation measure based on quote prices. The (inverse) measure we call Opportunity-Profit, which we calculate for the platinum futures price per minute in each day session interval s as the difference between the best bid and ask price across the Japan and U.S. market relative to the mid price of the Japan market. I interpret the maximum Opportunity-Profit as an inverse proxy for arbitrage activity. If this difference is not positive, we set $Profit_s$ to 0. Opportunity-Profit is calculated as:

$$Profit_s = \max \left(\frac{1}{T}\sum_{t=1}^{T}\frac{Bid_{JP,t}-Ask_{US,t}\times USDJPY_t}{Mid_{JP,t}}, \frac{1}{T}\sum_{t=1}^{T}\frac{Bid_{US,t}\times USDJPY_t-Ask_{JP,t}}{Mid_{JP,t}}, 0\right) \quad (4.1)$$

where $Bid_{i,t}$, $Ask_{i,t}$ and $Mid_{i,t}$ are the last bid, ask and mid-quote price in minute t in platinum market $(i = JP, US)$, all the price is converted to JPY/kg using the respective currency and weight pair. Opportunity-Profit is an inverse measure of arbitrage activity, because illiquidity hampers arbitrage one would expect less arbitrage activity when illiquidity is high.

Figure 4.1: Opportunity-Profit





4.2.2 Price Discovery Measures

To determine the relative contributions of Tokyo and New York to price discovery, we use Gonzalo and Granger's (1995) common factor component weight (GG). The GG models start from the estimation of the following VECM:

$$\Delta p_t = \mu + \alpha\beta' p_{t-1} + \sum_{k=1}^{n} A_k \, \Delta p_{t-k} + e_t \qquad (4.2)$$

where $p_t = (p_{1t}, p_{2t})$ represent the log-prices of the two markets, which are closely linked by arbitrage, and I(1) (integrated of order 1), so that the difference Δp_t are the respective returns at time t and stationary.

The vector α contains the error correction coefficients, and $z_{t-1} = \beta' p_{t-1}$ is the error correction term, which is stationary, therefore, β is considered a linear basis for the set of cointegrating vector, and k is the lag length determined by AIC. The α coefficients interpret as speed of adjustment. The μ in the error correction term is a vector of mean errors and captures systematic differences in the prices. From an economic perspective, the mean error is the target of the adjustment process.

Gonzalo and Granger (1995) proposed using the permanent-transitory decomposition of p_t to measure a market's contribution to price discovery. The specification is closely related to the common trend representation found in Stock and Watson (1988),

$$p_t = f_t + g_t \qquad (4.3)$$

where the common vector f_t is the permanent part and I(1), and g_t is the transitory part and stationary. Gonzalo and Granger (1995) assume that there is no long-run Granger causality from g_t to f_t, and define the common vector f_t to be a linear combination of the prices p_t,

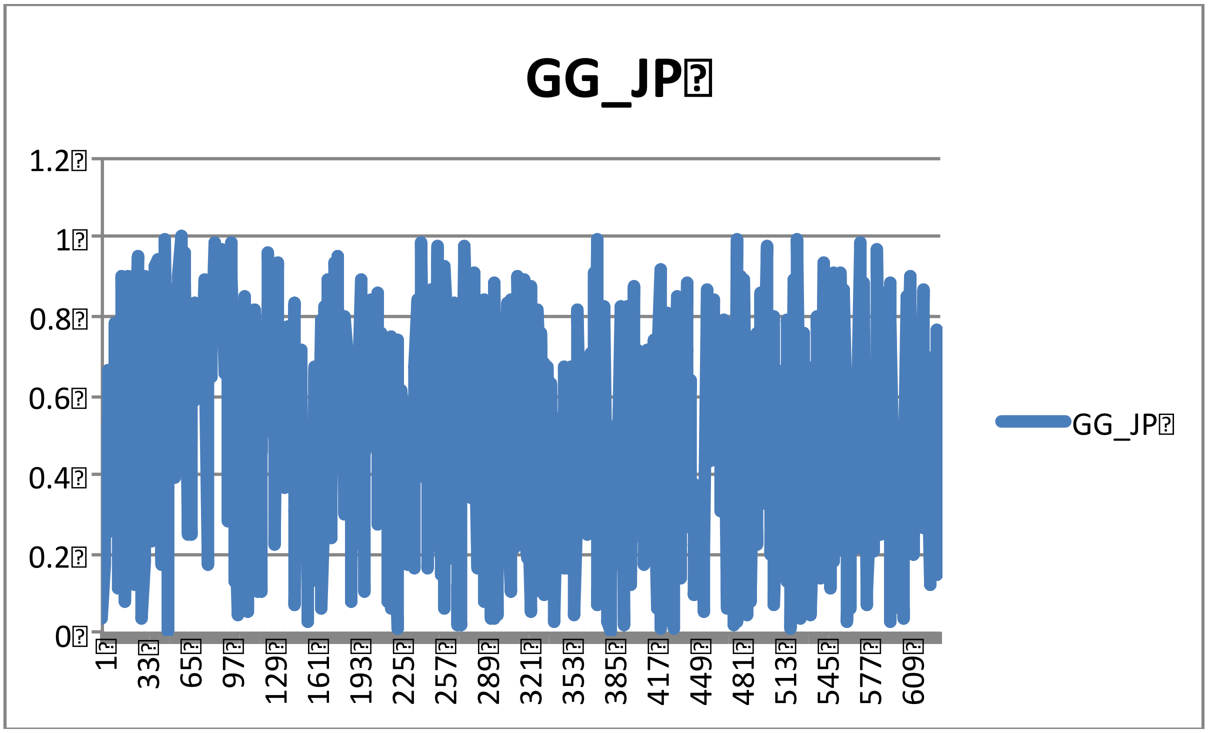
$$f_t = \gamma' p_t \qquad (4.4)$$

where $\gamma = (\gamma_1, \gamma_2)$, which is directly related to $\alpha_\perp$, the orthogonal matrices of α. As a result, the GG measures can also be defined in terms of the elements of γ as,

$$GG_i = \frac{|\gamma_i|}{|\gamma_1| + |\gamma_2|} \qquad (4.5)$$

The GG measures shows that as the dominant market switches from time to time, the price discovery is unstable, both Tokyo and New York market are considered internationally important venues for platinum trade, and participants include the major speculators and hedgers.

Figure 4.2: GG Measures



4.2.3 Liquidity Measures

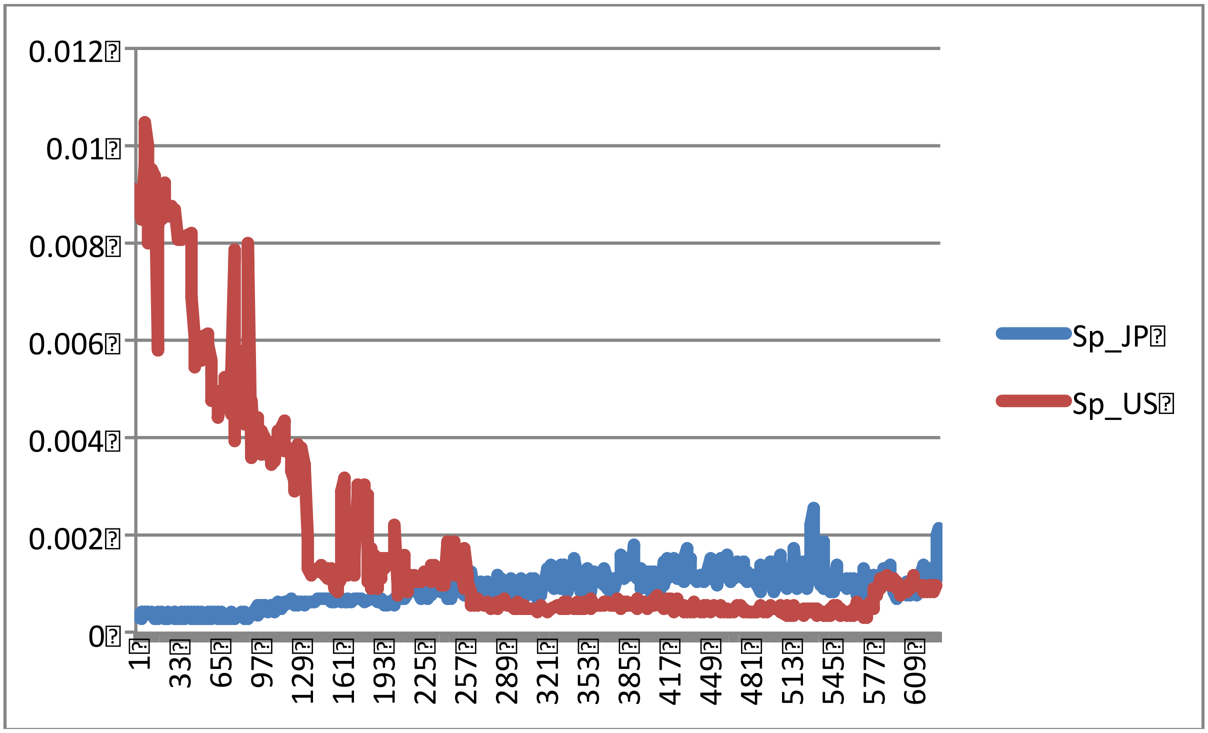
We assess the liquidity of the Tokyo and New York markets by calculating four measures: Spread, Zero trading volume ratio, the Amivest measure and trading volume. The first two measures can be interpreted as measures of illiquidity, the higher their value the more illiquid a market is. A higher value of the last two measures suggests a more liquid market.

Spread is calculated as follows:

$$Spread_{i,s} = \frac{1}{T}\sum_{t=1}^{T}\frac{Ask_{i,t}-Bid_{i,t}}{Mid_{i,t}} \qquad (4.6)$$

$$Mid_{i,t} = \frac{Bid_{i,t}+Ask_{i,t}}{2} \qquad (4.7)$$

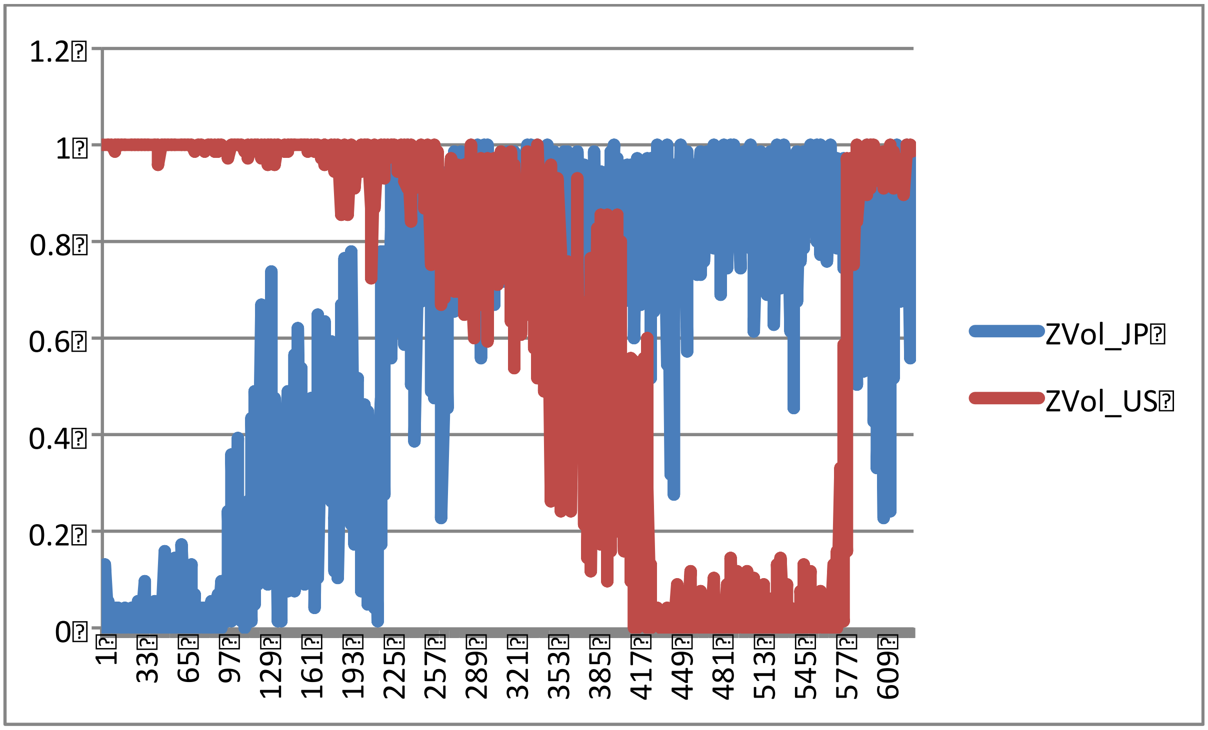
Figure 4.3 Spread



Liquidity can be also measured by the proportion of 5-min zero-volume in each day sessions. Large numbers of 5-min no-trade intervals suggest low liquidity. We believe that the proportion of 5-min zero-volume can measure the occurrence of the no-trade phenomenon. Zero-volume measure is calculated as follows:

$$ZVol_{i,s} = \frac{5}{T} \times Number\ of\ 5\ minutes\ zero\ volumes \qquad (4.8)$$

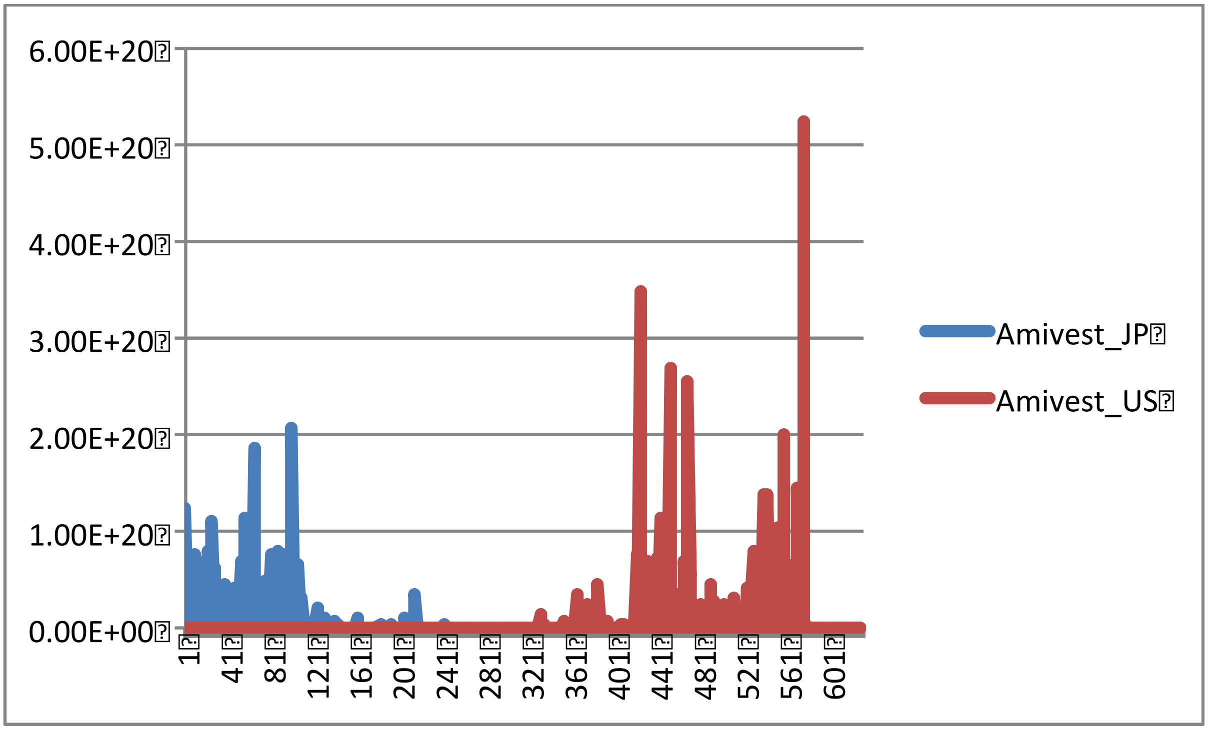
Figure 4.4 Zero-volume Measures



Amivest measure is calculated as an average for each day session interval of 5-minute trading volume by weight of metal in kilograms $Vol_t(5)(kg)$ divided by the absolute value of 5-minute returns $r_{i,t}(5)$,

$$Aminvest_{i,s} = \frac{5}{T}\sum_{t=1}^{T/5}\frac{Vol_{i,t}(5)(kg)}{|r_{i,t}(5)|} \qquad (4.9)$$

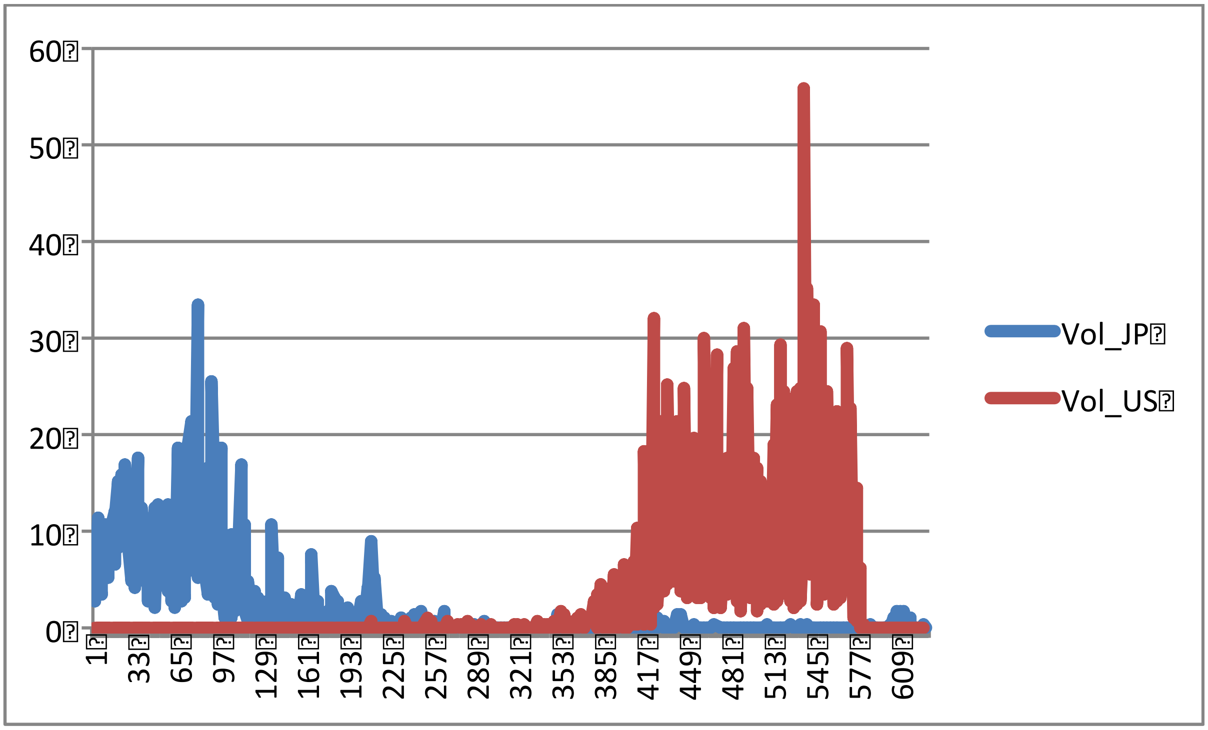
Figure 4.5 Amivest Measures



Trading volume (Vol) represents the average number of contracts traded per minute in each day session interval. $Vol_{i,t}(unit)$ represents the number of contracts traded on the relevant exchange during each minute t of our sample.

$$Vol_{i,s} = \frac{1}{T}\sum_{t=1}^{T} Vol_{i,t}(unit) \qquad (4.10)$$

Figure 4.6 Trading Volume



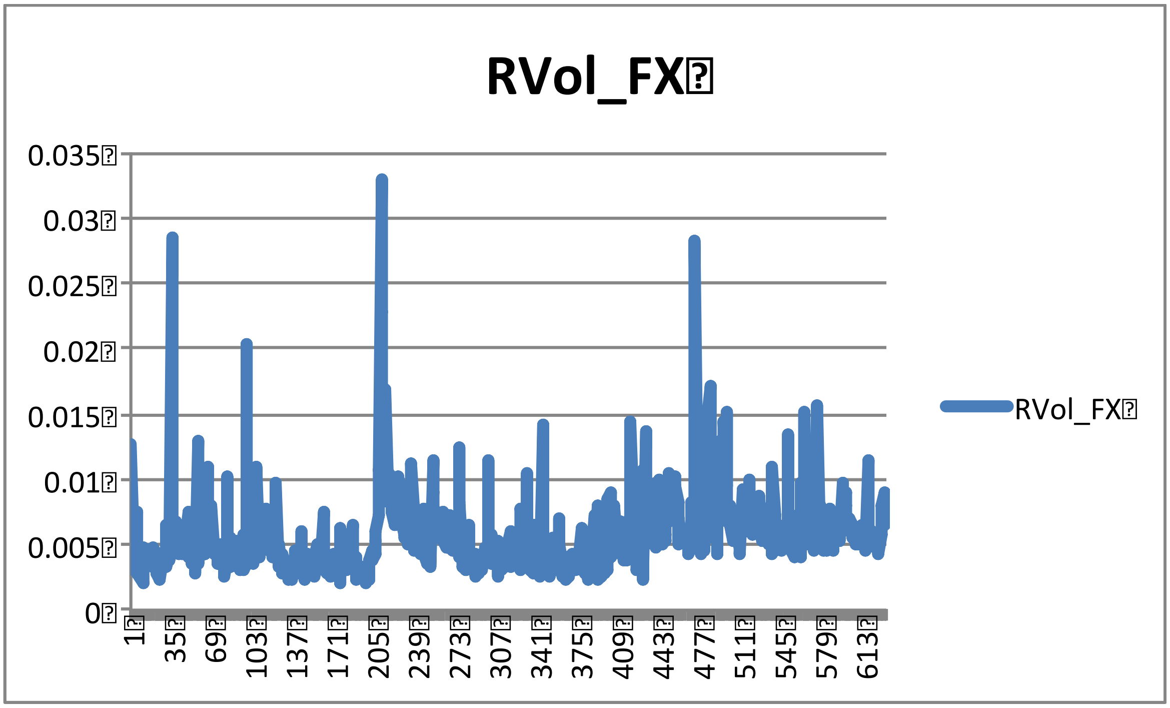
4.2.4 Exchange Rate Volatility

Realized Volatility of exchange rate is calculated as follows:

$$r_t = \log USDJPY_t - \log USDJPY_{t-1} \qquad (4.11)$$

$$RVol\_FX_s = \sqrt{\frac{1065}{T}\sum_{t=1}^{T} r_t^2} \qquad (4.12)$$

Figure 4.7 Exchange Rate Volatility



Summary statistics for each variable are shown in Tables 4.1.1 and 4.1.2 for platinum, respectively. Statistics for the variables related to contracts on TOCOM are denoted “JP”, and those relating to contracts on the New York exchanges are denoted “US”.

[Insert Table 4.1.1 here]

[Insert Table 4.1.2 here]

4.2.5 Models

We use a SEM (simultaneous equation model) with the 3SLS (three-stage least squares) to estimate the relationship between liquidity and arbitrage, and liquidity and price discovery. A set of dummy variables are used as the instrumental variables for the liquidity difference, Opportunity-Profit and GG measure ratio, which should be uncorrelated with the error term.

Session dummy variables reflect the daytime trading sessions in Tokyo, London and New York, and Maturity dummy variables reflect the maturity of the futures contract. As shown in the Table A4.1, the results suggest that Session and Maturity dummies can explain the liquidity difference well. But not all the dummy variables are good explanatory variables for Opportunity-Profit and GG measure ratio.

[Insert Table A4.1 here]

As the Opportunity-Profit is no-negative, we use the absolute value of liquidity difference. Spread does not have null values, so that spread difference is calculated as follows:

$$Spread_s = \log(\frac{Spread_{JP,s}}{Spread_{US,s}}) \qquad (4.13)$$

Because the other liquidity measures sometimes equals to zero, the other liquidity difference is defined as follows:

$$Liq_s = \log(\frac{1+Liq_{JP,s}}{1+Liq_{US,s}}) \qquad (4.14)$$

where $(Liq = ZVol, Amivest, Vol)$, and the SEM for relationship between liquidity and arbitrage can be represented by the following equations,

$$Profit_t = \alpha + \beta|Liq_t| + \sum_{k=1}^{n}(\gamma_k\, Profit_{t-k} + \delta_k|Liq_{t-k}|) + \theta RVol\_FX_t + \varepsilon_t \qquad (4.15)$$
$$|Liq_t| = \alpha + \beta Profit_t + \sum_{k=1}^{n}(\gamma_k\, Profit_{t-k} + \delta_k|Liq_{t-k}|) + \varepsilon_t \qquad (4.16)$$

Lagged dependent and independent variables, $RVol\_FX_t$ and Session and Maturity dummies are used as instrumental variables in both equations, but $RVol\_FX_t$ as independent variable in Eq. (4.15).

The GG measure ratio is calculated as follows:

$$GG_s = \log(\frac{GG_{JP,s}}{GG_{US,s}}) \qquad (4.17)$$

and the SEM for relationship between liquidity and price discovery can be represented by the following equations,

$$GG_t = \alpha + \beta Liq_t + \sum_{k=1}^{n}(\gamma_k\, GG_{t-k} + \delta_k Liq_{t-k}) + \varepsilon_t \qquad (4.18)$$
$$Liq_t = \alpha + \beta GG_t + \sum_{k=1}^{n}(\gamma_k\, GG_{t-k} + \delta_k Liq_{t-k}) + \theta Trend + \varepsilon_t \qquad (4.19)$$

because the liquidity difference has monotonically increasing (Spread and Zero-Volume measure) or decreasing (Amivest measure and Volume) by time, which can be seen from the variable Figures, we use time-trend as independent variable in Eq.(4.19).

4.3 Empirical Results

We take the Opportunity-Profit and Exchange Rate Volatility multiplied by 100 (as a percentage) and Amivest measure difference divided by 100 to make all the variables have similar order of magnitude. Using SBIC (Schwarz Bayesian information criterion) to determine the appropriate length of lags, and 3-lag model was selected and reported as the appropriate model.

[Insert Table 4.2.1 here]

[Insert Table 4.2.2 here]

Table 4.2.1 and Table 4.2.2 provide the SEM results for relationship between liquidity and arbitrage. Both the coefficients β (Spread, Amivest measure and Volume) of $|Liq_t|$ in Eq. (4.15) and of $Profit_t$ in Eq. (4.16) are positive and significant, while being insignificant for Zero-Volume measure, which suggests that large liquidity difference between Tokyo and New York platinum futures market corresponds to high Opportunity-Profit in the same day session intervals and vice versa. Improvement in liquidity difference decreases the arbitrage activity between Tokyo and New York.

Platinum are actively traded in Tokyo and inactively traded in New York in deferred contract months. At the beginning of the 1-year maturity, New York market is much more illiquid, Tokyo market attracts most of liquidity and informed traders and that trading becomes more concentrated, the arbitrage activity between Tokyo and New York becomes less, then increase in the Opportunity-Profit. But also information asymmetry occurs in the same period, arbitrage opportunities arise as a result of differences in information between Tokyo and New York, arbitrageurs should increase adverse selection and impair liquidity.

As time has passed, the difference of liquidity between Tokyo and New York decreases, that pricing information transmissions for platinum futures contracts are strong and rapid across the two markets. Arbitrage opportunities arise as a result of non-fundamental demand shocks, arbitrageurs should act as cross-sectional market makers and improve liquidity, the arbitrage activity between the Tokyo and New York becomes more, which leads to lower Opportunity-Profit.

We observes that lots of the coefficient estimates on the first and third lagged $AbsLiq_{t-k}$ terms in Eq. (4.15) and $Profit_{t-k}$ terms in Eq. (4.16) is statistically significant, most of them are negative, which suggests that high liquidity difference (Opportunity-Profit) leads to low Opportunity-Profit (liquidity difference) in the following day session interval or day, because of pricing information transmissions and arbitrage activity between the Tokyo and New York platinum futures market.

[Insert Table 4.2.3 here]

[Insert Table 4.2.4 here]

Table 4.2.3 and Table 4.2.4 report the SEM results for relationship between liquidity and price discovery, which also yield two important observations. First, the coefficients β (Spread and Zero-Volume measure) of Liq_t are negative and significant, and while being positive and significant for Amivest measure and Volume, which suggests that the more liquid market is expected to be more important in price discovery. As the higher value of Spread and Zero-Volume measure, the more illiquid a market is, and the higher value of Amivest measure and Volume the more liquid suggests the more liquid market, this implies an increase of liquidity in the Tokyo relative to New York leads to a higher contribution of the Tokyo market to price discovery. The coefficients β (Spread and Zero-Volume measure) of GG_t are negative and significant, and while being positive and significant for Amivest measure and Volume, which suggests that an increase in price discovery leads to better liquidity in the same day session interval.

Second, we observe that most of GG_t is related to the third lagged terms Liq_{t-3} with a coefficient, Spread and Zero-Volume measure are positive, and Amivest measure and Volume are negative. A positive change of liquidity in the Tokyo relative to New York over the previous three day session intervals (one day) leads to a negative change in GG measure of Tokyo. This indicates that the dominant market switches from Tokyo to New York as the time goes on, rapid pricing information transmissions and high-frequency arbitrage activity might be the possible causes. Some of the coefficient estimates on the third lagged terms GG_{t-3} are also statistically significant, Spread is positive, and Amivest measure and Volume are negative, which suggests that improvements in price discovery leads to a decrease in the relative liquidity measure.

4.4 Conclusion

In this chapter, we use 1-minute data for platinum futures contracts of the same maturity from May 2015 to April 2016 traded on TOCOM and NYMEX, consisting of bid and ask prices and trading volumes to construct the arbitrage profit, price discovery, and liquidity measures, to examine intraday relationships between liquidity and arbitrage, and liquidity and price discovery. To accommodate both lagged and contemporaneous relations among the variables, we estimate a SEM with the 3SLS.

Two conclusions are implied by the paper's results. First, We find that an increase in arbitrage activity is associated with a reduction in market liquidity imbalance between Tokyo and New York, while an improvement in liquidity difference leads to increased arbitrage profit. This finding provides support for the view that arbitrageurs tend to trade against temporary demand shocks and thus enhance market integration and liquidity. High liquidity difference (Opportunity-Profit) leads to low Opportunity-Profit (liquidity difference) in the following day session interval or day, because of pricing information transmissions and arbitrage activity across the Tokyo and New York platinum futures market.

Second, We find that liquidity is related to price discovery. An increase in liquidity (Amivest measure and Volume) and a decrease in illiquidity (Spread and Zero-volume measure) in one market relative to another increase the contribution of that market to price discovery. This finding implies that the market which provides better liquidity will become more important in terms of price discovery. This impact occurs within the same day session intervals. Conversely, we also find that an increase in price discovery leads to improved liquidity, indicating that the market which leads in terms of price discovery attracts more liquidity.

Table 4.1.1: Summary Statistics

Statistics	Prof_JP	Prof_US	Prof	GG_JP	GG_US	Sp_JP	Sp_US
Mean	0.0031	-0.0059	0.0037	0.4905	0.5095	0.0009	0.0019
Median	0.0037	-0.0071	0.0037	0.4664	0.5336	0.0009	0.0007
Minimum	-0.005	-0.0142	0	0.0051	0.0006	0.0003	0.0003
Maximum	0.0107	0.003	0.0107	0.9994	0.9949	0.0026	0.0105
Stdev	0.0039	0.0042	0.0031	0.2749	0.2749	0.0003	0.0024
Skewness	-0.1904	0.425	0.1068	0.0315	-0.0315	0.3492	1.9041
Kurtosis	-1.3621	-1.1549	-1.5026	-1.1643	-1.1643	0.6380	2.5933
nobs	630	630	630	630	630	630	630

Note: Prof_JP, Prof_US and Prof is the Opportunity-Profit; GG_JP and GG_US is the GG measures; Sp_JP and Sp_US is the spread.

Table 4.1.2: Summary Statistics

Statistics	ZVol_JP	ZVol_US	Amivest_JP	Amivest_US	Vol_JP	Vol_US	RVol_FX
Mean	0.6157	0.6672	4.91088E+18	6.34095E+18	2.0333	3.1601	0.0057
Median	0.7681	0.9275	4152.3945	1392.794	0.2154	0.0609	0.005
Minimum	0	0	0	0	0	0	0.0021
Maximum	1	1	2.06E+20	5.26E+20	33.512	55.7478	0.0329
Stdev	0.3604	0.4078	1.79478E+19	3.35407E+19	4.0922	6.8599	0.0031
Skewness	-0.6355	-0.7659	6.2556	9.8184	2.9571	2.9347	3.3986
Kurtosis	-1.1827	-1.2007	50.511	119.6732	10.8347	10.1067	19.6619
nobs	630	630	630	630	630	630	630

Note: ZVol_JP and ZVol_US is the zero-volume measures; Amivest_JP and Amivest_US is the Amivest measures; Vol_JP and Vol_US is the trading volume; RVol_FX is the Realized Volatility of exchange rate.

Table 4.2.1: SEM Estimation Results (Arbitrage and Liquidity)

Dependent Variable	Profit		AbsSp		Profit		AbsZVol	
Intercept	-0.0072		0.0276		0.0166	*	0.0085	
AbsLiq	0.342	***			0.0837			
Profit			2.4229	***			0.0708	
AbsLiq(-1)	-0.1225	***	0.3601	***	-0.0104		0.0595	***
Profit(-1)	0.8674	***	-2.1324	***	0.8082	***	-0.0987	
AbsLiq(-2)	0.0003		0.0063		-0.003		0.0448	**
Profit(-2)	0.002		-0.0235		-0.0477		0.0673	
AbsLiq(-3)	-0.2063	***	0.5963	***	-0.0717		0.8716	***
Prof(-3)	0.1246	**	-0.2596	*	0.2172	***	-0.0435	
RVol_FX	-0.0028				-0.0127			
Adjusted R2	0.8702		0.8797		0.9498		0.8957	

Note: Prof is the Opportunity-Profit; AbsSp is the absolute value of spread difference; AbsZVol is the absolute value of Zero-volume measures difference; ***, **, and * denote significance of the coefficient at the 1, 5 and 10 percent levels, respectively.

Table 4.2.2: SEM Estimation Results (Arbitrage and Liquidity)

Dependent Variable	Profit	AbsAmivest	Profit	AbsVol
Intercept	-0.0102	0.1158 ***	0.0093	0.0241
AbsLiq	0.1617 ***		0.1876 ***	
Profit		0.9602 ***		2.8262 ***
AbsLiq(-1)	-0.0326 *	0.1402 ***	-0.0156 ***	0.0754 ***
Profit(-1)	0.7924 ***	-0.7114 **	0.8325 ***	-2.4237 ***
AbsLiq(-2)	-0.0091	0.1287 ***	0.0028	-0.0013
Profit(-2)	-0.055	0.1479	-0.0161	-0.0276
AbsLiq(-3)	-0.028	0.281 ***	-0.1703 ***	0.8965 ***
Prof(-3)	0.2462 ***	-0.4033 ***	0.1689 ***	-0.3673
RVol_FX	-0.0116		-0.013	
Adjusted R2	0.942	0.0007	0.9063	0.8486

Note: Prof is the Opportunity-Profit; AbsAmivest is the absolute value of Amivest measures difference; AbsVol is the absolute value of trading volume (Unit) difference; ***, **, and * denote significance of the coefficient at the 1, 5 and 10 percent levels, respectively.

Table 4.2.3: SEM Estimation Results (Price discovery and Liquidity)

Dependent Variable	GG		Spread		GG		ZVol	
Intercept	-0.0742		-0.0326		-0.0277		0.0103	
Liq	-2.707	***			-9.3116	***		
GG			-0.3623	***			-0.0519	***
Liq(-1)	0.928	***	0.3433	***	0.5115		0.0605	***
GG(-1)	0.0121		0.0043		0.042		0.0024	
Liq(-2)	-0.0199		-0.0069		0.1804		0.0316	
GG(-2)	0.0482		0.0175		0.0501		0.0024	
Liq(-3)	1.5398	***	0.5674	***	7.9962	***	0.8808	***
GG(-3)	0.1118	***	0.0405	***	0.1066	***	0.0046	
Trend			0				0	
Adjusted R2	-0.0848		0.7896		-0.1689		0.9371	

Note: GG is the GG measure ratio; Sp is the spread difference; ZVol is the Zero-volume measures difference; ***, **, and * denote significance of the coefficient at the 1, 5 and 10 percent levels, respectively.

Table 4.2.4: SEM Estimation Results (Price discovery and Liquidity)

Dependent Variable	GG		Amivest		GG		Volume	
Intercept	-0.1112	*	0.0544	**	-0.004		-0.0125	
Liq	4.8089	***			2.5843	***		
GG			0.1729	***			0.3183	***
Liq(-1)	-1.274	***	0.2378	***	-0.092		0.0414	
GG(-1)	0.0708	*	-0.0133	**	0.0236		-0.0066	
Liq(-2)	-0.2381		0.0645		-0.0474		0.0215	
GG(-2)	0.0403		-0.0072		0.073	*	-0.0246	*
Liq(-3)	-1.8999	***	0.3846	***	-2.242	***	0.8737	***
GG(-3)	0.1123	***	-0.0193	***	0.0931	**	-0.0275	*
Trend			-0.0001				0	
Adjusted R2	-0.16		-0.111		-0.3318		0.8394	

Note: GG is the GG measure ratio; Amivest is the Amivest measure difference; Vol is the trading volume (Unit) difference; ***, **, and * denote significance of the coefficient at the 1, 5 and 10 percent levels, respectively.

Table A4.1 OLS Estimation Results (Liquidity)

Dependent Variable	Sp		ZVol		Amivest		Vol	
Intercept	-3.0274	***	-0.7988	***	0.4825	***	2.7961	***
SD2	0.1603	**	0.1491	***	-0.0886	***	-0.5866	***
SD3	0.3083	***	0.2489	***	-0.1504	***	-1.0948	***
MD2	1.4139	***	0.177	***	-0.0716	**	-1.0035	**
MD3	2.0644	***	0.288	***	-0.1039	***	-1.4338	***
MD4	2.9801	***	0.617	***	-0.3441	***	-2.1571	***
MD5	3.5511	***	0.8486	***	-0.4913	***	-2.7435	***
MD6	3.7955	***	1.247	***	-0.6753	***	-4.4046	***
MD7	3.7869	***	1.28	***	-0.6824	***	-4.3286	***
MD8	3.4454	***	0.9458	***	-0.5088	***	-3.3883	***
Adjusted R2	0.9147		0.8485		0.6368		0.823	

Note: Sp is the spread difference; ZVol is the Zero-volume measures difference; Amivest is the Amivest measure difference; Vol is the trading volume (Unit) difference; SD is the Session dummy; MD is the Maturity dummy; ***, **, and * denote significance of the coefficient at the 1, 5 and 10 percent levels, respectively.

The OLS liquidity can be represented by the following equation,

$$Liq_{k,i,j} = \alpha_{k,1,1} + \sum_{i=2}^{3} \beta_{k,i} SD_i + \sum_{j=2}^{9} \gamma_{k,j} MD_j + \varepsilon_{k,i,j} \qquad \text{(A4.1)}$$

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Acknowledgement

During the periods of my life and study in Japan, I have received a lot of help, support and encouragement from many people. Without their continuous support, warm encouragement, and insightful comment, I could not complete this thesis. Here, I have a chance to express my great gratitude to them.

First of all, I would like to show my deepest gratitude to my supervisor, Prof. Kentaro Iwatsubo for the continuous supports, warm encouragements, insightful comments, and constructive suggestions during the whole period of my Ph.D. study in Japan. He encouraged me a lot when I encountered confusions.

Besides my advisor, I would like to thank the rest of my thesis committee: Prof. Clinton Watkins and Prof. Masahiko Shibamoto, for giving me generous support regarding econometric issues and explanations of this thesis on improving of this thesis.

I thank all the members in Iwatsubo seminar for all the fun we have had during the last 5 years. I also want to express my good friend Dr. Teng Ma for the stimulating discussions.

Finally, I would like to express thanks to my parents and all my friends for supporting me spiritually throughout writing this thesis and my life in general.