Teaching The Bid-Ask Spread And Triangular Arbitrage For The Foreign Exchange Market

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ABSTRACT

The foreign exchange (FX) market is an important chapter in international finance. Understanding the market microstructure is critical for learning the FX market. To assist students better understand the FX market microstructure, an instructor can use an event study with minute-by-minute quote data provided in the Excel assignment, asking students to investigate the impact of an event on the bid-ask spread and triangular arbitrage opportunities. This pedagogical paper provides two examples of making the Excel assignment for reference.

Keywords: Foreign Exchange; Bid-Ask Spread; Triangular Arbitrage

INTRODUCTION

Understanding the foreign exchange (FX) market is essential for learning international finance. Eun and Resnick (2015) describe the FX market's structure, participants, and quotations. The FX market is a decentralized or over-the-counter (OTC) market without common trading floor. The FX market is open 24 hours a day. There are several financial centers with different time zones in the world. When the trading of one currency is closed at one financial center, it continues on the other financial center with the different time zone. International banks serve as dealers who make a market by standing ready to buy or sell foreign currencies for their own accounts. The bid price represents the price a bank dealer is willing to buy for a currency and the ask price is the price a bank dealer is willing to sell for a currency. Therefore, bank clients buy at the ask price from the dealer and sell at the bid price to the dealer. The bid-ask spread, the difference between the ask price and the bid price, is the compensation (transaction cost) to the dealer (bank clients). The bid-ask spread and bid-ask relationship are basic parts of the FX market microstructure. Students who are familiar with these topics are able to better comprehend the theory and practice of the FX market.

To assist students better understand the FX market microstructure in international finance, an instructor can give students an Excel assignment that asks them to (1) calculate the spot FX bid-ask spreads before, around, and after an event to see whether they are significantly different, and (2) examine whether an event affects triangular arbitrage opportunities. In this pedagogical paper, two examples of making the Excel assignment are provided for reference.

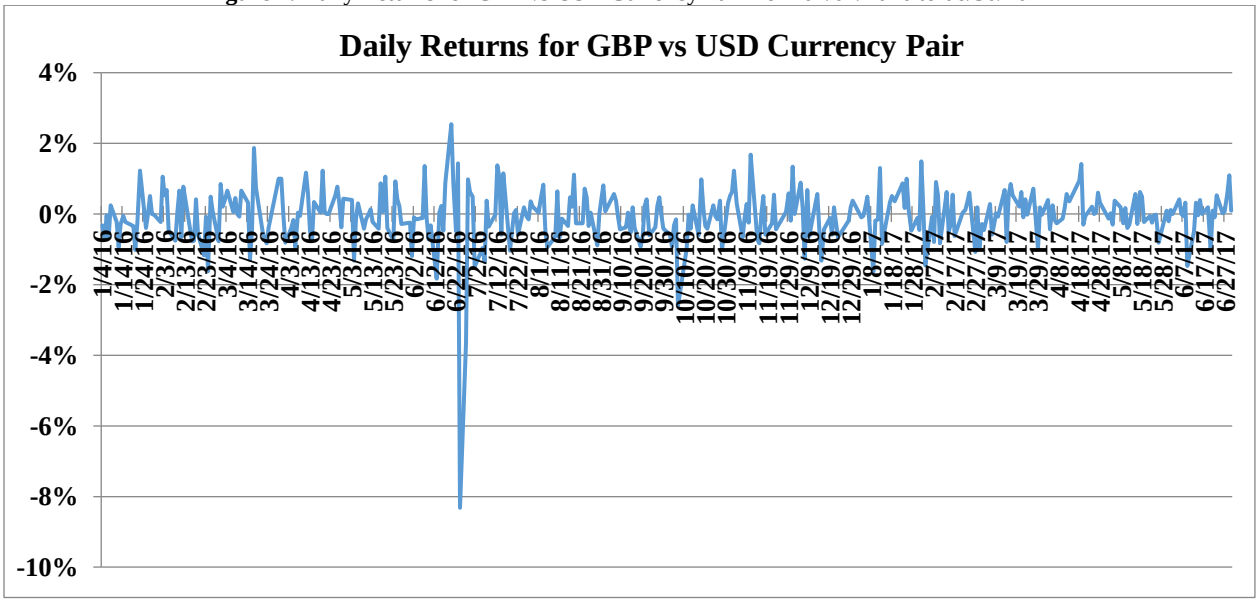
THE BID-ASK SPREAD

Huang and Masulis (1999) use the tick-by-tick quote data of the spot Deutsch Mark vs U.S. Dollar (DM vs USD) currency pair from October 1, 1992 to September 29, 1993 to investigate the effects of the dealer competition on bid-ask spreads in the FX market. They find that bid-ask spreads increase when the FX volatility increases, and they decrease when the dealer competition increases.

In an Excel assignment, an instructor can use an event study to ask students to examine whether the bid-ask spread goes up when the event makes the FX market more volatile. For instance, the U.K. held a referendum on June 23, 2016 to decide whether Britain should stay in the European Union (EU). The result was shocking; 52% voted to leave the EU. The unexpected outcome of the Brexit vote caused stock markets in Asia, Europe, and the U.S. to drop sharply

and resulted in turmoil of the FX market (Cheng, 2016; Gold and Bird, 2016). The Brexit vote can be used for an event study to see how it affects the bid-ask spread of trading the British pound vs U.S. dollar (GBP vs USD) currency pair. From the International Monetary Fund (IMF) exchange rates database website, we can retrieve the British pound vs U.S. dollar (GBP vs USD) currency pair daily exchange rate data (the price of one British pound in U.S. dollars) from the beginning of January 2016 (01/04/2016) to the end of June 2017 (06/30/2017). Then, the daily exchange rate returns are calculated by taking the first difference of natural logarithm of daily exchange rates. The chart of daily returns of GBP vs USD currency pair is shown on Figure 1.

Figure 1. Daily Returns for GBP vs USD Currency Pair from 01/04/2016 to 06/30/2017



This figure shows the time series plots for the daily exchange rate returns for GBP vs USD currency pair from 01/04/2016 to 06/30/2017. The daily exchange rate returns are calculated by taking the first difference of natural logarithm of daily exchange rates.

The Brexit vote was held on June 23, 2016. Figure 1 shows greater return volatility around the Brexit vote; the return was greater than 1% (1.44%) on the vote date but it fell down to less than negative 8% (–8.32%) on June 24, 2016, followed by –3.66% on June 27, 2016 and 0.98% on June 28, 2016. In the Excel assignment, these four days around the Brexit vote [June 23 (Thursday), June 24 (Friday), June 27 (Monday), and June 28, 2016 (Tuesday)] can be identified as the high volatility period. Before the Brexit vote, for example, the returns were stable during the four-day period [May 12 (Thursday), May 13 (Friday), May 16 (Monday), and May 17, 2016 (Tuesday)]. After the Brexit vote, for instance, the returns became stable during the four-day period [July 21 (Thursday), July 22 (Friday), July 25 (Monday), and July 26, 2016 (Tuesday)]. These two four-day periods can be regarded as low volatility (regular) periods.[1]

To investigate whether the bid-ask spread is significantly higher during the high volatility period, quote (tick-by-tick) data with bid and ask prices for GBP vs USD currency pair are needed and they can be purchased from Tick Data, LLC. The trading of FX is 24 hours a day. The quote data from Tick Data are time stamped to the millisecond (HH:MM:SS.mmm) and start at the first millisecond of 6 PM (18:00:00.001) Eastern Time (ET) on Sunday and end at the last millisecond of 5:59 PM (17:59:59.999) ET on Friday for each week. So, Tick Data classifies one-day 24-hour trading as 18:00:00.001 ET on the previous date to 17:59:59.999 ET on the current day. For example, the 24-hour trading time on June 23, 2016 is from 18:00:00.001 ET on June 22, 2016 to 17:59:59.999 ET on June 23, 2016.

[1] This example uses four days for each high or low volatility period. The instructor can decide which dates and number of days for each time period. It is suggested that number of days, starting weekday (for example, Thursday), and ending weekday (for example, Tuesday) in each time period should be consistent.

To make it simple for students, an instructor can program on the statistical software to select only the closing quote for each minute from the quote data and export minute-by-minute closing quotes to an Excel file to make the assignment's data.[2]

The Excel assignment file includes minute-by-minute closing quotes (with bid and ask prices) during the four-day high volatility period (days around the Brexit vote) and two four-day low volatility periods (days before and days after the Brexit vote). Based on the Excel assignment file, students are asked to calculate the bid-ask spread for each minute of each day during high and low volatility periods and then conduct Paired t-Test (t-Test: Paired Two-Sample for Means) using Data Analysis function in Excel to see whether the bid-ask spread is significantly greater during the high volatility period than that during the low volatility periods. The bid-ask spread can be computed as follows:

$$Quoted\ Spread = A_t - B_t\ , \quad (1)$$

$$Percentage\ Quoted\ Spread = (A_t - B_t)/M_t \quad (2)$$

where B_t and A_t are bid price and ask price at time t and $M_t = (B_t + A_t)/2$ is the quoted midpoint at time t. The bid and ask prices at time t represent the closing quote of the previous minute, time $t-1$. The FX trading is 24 hours, 1440 minutes each day. The mean bid-ask spread per day is the average of all minute bid-ask spreads per day. The calculation results are summarized in Table 1.

Table 1. Mean Quoted and Percentage Quoted Spreads in High and Low Volatility Periods

Date	# of Minutes	Mean Quoted Spread	Mean % Quoted Spread
High Volatility Period (Days Around the Brexit Vote)			
06/23/2016 (Thursday)	1440	$0.000233	0.0157%
06/24/2016 (Friday)	1382	$0.000333	0.0240%
06/27/2016 (Monday)	1440	$0.000237	0.0178%
06/28/2016 (Tuesday)	1440	$0.000187	0.0140%
Low Volatility Period (Regular Days Before the Brexit Vote)			
05/12/2016 (Thursday)	1440	$0.000125	0.0086%
05/13/2016 (Friday)	1381	$0.000112	0.0078%
05/16/2016 (Monday)	1440	$0.000119	0.0083%
05/17/2016 (Tuesday)	1440	$0.000123	0.0085%
Low Volatility Period (Regular Days After the Brexit Vote)			
07/21/2016 (Thursday)	1440	$0.000153	0.0116%
07/22/2016 (Friday)	1381	$0.000146	0.0110%
07/25/2016 (Monday)	1440	$0.000152	0.0116%
07/26/2016 (Tuesday)	1440	$0.000129	0.0099%

Note: On 06/24/2016, there is no quote available after 17:01 ET, except 17:04 ET. So, number of minutes is 1382 (= 1440 – 58). On 05/13/2016 and 07/22/2016, there is no quote available after 17:01 ET. So, number of minutes is 1381 (= 1440 – 59).

Table 1 shows that mean quoted spreads and percentage quoted spreads in the high volatility period (days around the Brexit vote) are greater than those in the low volatility (regular days before and regular days after the Brexit vote) periods. There are four days for each time period. To test whether the bid-ask spread is significantly greater during the high volatility period, an instructor can ask students to form same minute paired bid-ask spread data between the first-and-first (on Thursday), second-and-second (on Friday), third-and-third (on Monday), fourth-and-fourth (on Tuesday) days in high and low volatility periods and conduct Paired t-Test. The Paired t-Test results are summarized in Table 2A and 2B.

[2] For example, the bid and ask data on 19:01 ET represent the closing quote on the last millisecond of previous minute, 19:00 ET.

Table 2A. Paired t-Test (t-Test: Paired Two-Sample for Means) for Quoted Spreads

	High Volatility Period	Low Volatility Period	Low Volatility Period
Date (on Thursday)	**06/23/2016**	**05/12/2016**	**07/21/2016**
Mean	\$0.000233	\$0.000125	\$0.000153
Variance	2.3451×10^{-8}	1.4628×10^{-8}	1.3396×10^{-8}
T-Statistics (p-value)	24.3446^{***} (< 0.01) [Compare 06/23/2016 with 05/12/2016]		
T-Statistics (p-value)	18.1781^{***} (< 0.01) [Compare 06/23/2016 with 07/21/2016]		
Date (on Friday)	**06/24/2016**	**05/13/2016**	**07/22/2016**
Mean	\$0.000333	\$0.000112	\$0.000146
Variance	4.2234×10^{-8}	1.0138×10^{-8}	1.0880×10^{-8}
T-Statistics (p-value)	39.8532^{***} (< 0.01) [Compare 06/24/2016 with 05/13/2016]		
T-Statistics (p-value)	32.8845^{***} (< 0.01) [Compare 06/24/2016 with 07/22/2016]		
Date (on Monday)	**06/27/2016**	**05/16/2016**	**07/25/2016**
Mean	\$0.000237	\$0.000119	\$0.000152
Variance	2.9588×10^{-8}	1.2420×10^{-8}	1.4320×10^{-8}
T-Statistics (p-value)	24.1376^{***} (< 0.01) [Compare 06/27/2016 with 05/16/2016]		
T-Statistics (p-value)	18.0673^{***} (< 0.01) [Compare 06/27/2016 with 07/25/2016]		
Date (on Tuesday)	**06/28/2016**	**05/17/2016**	**07/26/2016**
Mean	\$0.000187	\$0.000123	\$0.000129
Variance	1.8711×10^{-8}	1.3056×10^{-8}	9.3328×10^{-9}
T-Statistics (p-value)	14.4555^{***} (< 0.01) [Compare 06/28/2016 with 05/17/2016]		
T-Statistics (p-value)	14.2338^{***} (< 0.01) [Compare 06/28/2016 with 07/26/2016]		

To perform Paired t-Test, the last quoted spread (at 17:04 ET) on 06/24/2016 is eliminated to be consistent with each minute (time) of the quoted spread on 05/13/2016 and 07/22/2016.
***: Significant at 1% level

Table 2B. Paired t-Test (t-Test: Paired Two-Sample for Means) for Percentage Quoted Spreads

	High Volatility Period	Low Volatility Period	Low Volatility Period
Date (on Thursday)	**06/23/2016**	**05/12/2016**	**07/21/2016**
Mean	0.0157%	0.0086%	0.0116%
Variance	1.0595×10^{-8}	7.0062×10^{-9}	7.6590×10^{-9}
T-Statistics (p-value)	23.4033^{***} (< 0.01) [Compare 06/23/2016 with 05/12/2016]		
T-Statistics (p-value)	13.3634^{***} (< 0.01) [Compare 06/23/2016 with 07/21/2016]		
Date (on Friday)	**06/24/2016**	**05/13/2016**	**07/22/2016**
Mean	0.0240%	0.0078%	0.0110%
Variance	2.1586×10^{-8}	4.8839×10^{-9}	6.2490×10^{-9}
T-Statistics (p-value)	40.9824^{***} (< 0.01) [Compare 06/24/2016 with 05/13/2016]		
T-Statistics (p-value)	31.2318^{***} (< 0.01) [Compare 06/24/2016 with 07/22/2016]		
Date (on Monday)	**06/27/2016**	**05/16/2016**	**07/25/2016**
Mean	0.0178%	0.0083%	0.0116%
Variance	1.6578×10^{-8}	6.0129×10^{-9}	8.3000×10^{-9}
T-Statistics (p-value)	26.4533^{***} (< 0.01) [Compare 06/27/2016 with 05/16/2016]		
T-Statistics (p-value)	17.5880^{***} (< 0.01) [Compare 06/27/2016 with 07/25/2016]		
Date (on Tuesday)	**06/28/2016**	**05/17/2016**	**07/26/2016**
Mean	0.0140%	0.0085%	0.0099%
Variance	1.0576×10^{-8}	6.2399×10^{-9}	5.4202×10^{-9}
T-Statistics (p-value)	17.2028^{***} (< 0.01) [Compare 06/28/2016 with 05/17/2016]		
T-Statistics (p-value)	13.7110^{***} (< 0.01) [Compare 06/28/2016 with 07/26/2016]		

To perform Paired t-Test, the last percentage quoted spread (at 17:04 ET) on 06/24/2016 is eliminated to be consistent with each minute (time) of the percentage quoted spread on 05/13/2016 and 07/22/2016.
***: Significant at 1% level.

Table 2A and Table 2B summarize the Paired t-Test results for quoted spreads and percentage quoted spreads, respectively. Table 2A and Table 2B show that bid-ask spreads (both quoted and percentage quoted spreads) are significantly greater in high volatility period than those in low volatility periods at 1% level.[3] The results support that bid-ask spreads increase when the FX volatility increases.

TRIANGULAR ARBITRAGE

Eun and Resnick (2015) state "Triangular arbitrage is the process of trading out the U.S. dollar into a second currency, then trading it for a third currency, which is in turn traded for U.S. dollars. The purpose is to earn an arbitrage profit via trading from the second to the third currency when the direct exchange rate between the two is not in alignment with the cross-exchange rate (p. 127)." They also use an example to explain how to take advantage of a triangular arbitrage opportunity. Based on their definition of triangular arbitrage, assume euro (EUR, €) is the second currency and British pound (GBP, £) is the third currency. To prevent the triangular arbitrage opportunity, the ask price of the cross-rate (GBP vs EUR, €/£, amount of € per £) should be no less than (greater than or equal to) the bid price of the cross-rate (GBP vs EUR, €/£, amount of € per £), which means $Spot^{Ask}(€/£) \geq Spot^{Bid}(€/£)$.

If $Spot^{Ask}(€/£) < Spot^{Bid}(€/£)$, the arbitrage opportunity appears. (€/£) represents the amount of euro per British pound. $Spot^{Ask}(€/£)$ represents the price the dealer is willing to sell one British pound to receive the amount of euro. $Spot^{Bid}(€/£)$ represents the price the dealer is willing to buy one British pound by paying the amount of euro. If $Spot^{Ask}(€/£) < Spot^{Bid}(€/£)$, the dealer is willing to sell one British pound (£) for receiving less amount of euro (€) than what he/she is willing to pay to buy one British pound (£). This situation indicates that British pound (£) becomes less valuable (depreciates) relative to euro (€) from the dealer's viewpoint [or euro (€) becomes more valuable (appreciates) relative to British pound (£) from the dealer's viewpoint]. To earn a triangular arbitrage profit, a U.S. cross-rate trader can first convert USD ($) to euro (€) [sell $ to receive €], then convert the euro (€) to more British pound (£) [sell € to receive more £], and finally convert more British pound (£) to more U.S. dollar ($) [sell more £ to receive more $]. Assume no other trading costs, the arbitrage profit will be the amount of U.S. dollar ($) received eventually minus the amount of U.S. dollar ($) invested initially.

A numerical example to demonstrate above statements is as follows. Suppose bank dealer A posts a bid quote to buy £1 by paying $1.4871 [$Spot^{Bid}(\$/£) = 1.4871$] and at the same time, bank dealer B posts a bid quote to buy $1 by paying €0.8794 [$Spot^{Bid}(€/\$) = 0.8794$]. According to the spot FX mathematics for the cross-rate,

$$Spot^{Bid}(€/£) = Spot^{Bid}(\$/£) \times Spot^{Bid}(€/\$) \quad (3)$$

$Spot^{Bid}(€/£) = 1.4871 \times 0.8794 = 1.30775574$, based on equation (3). To prevent the triangular arbitrage opportunity, bank dealer C will post an ask quote to sell £1 for receiving not less than €1.30775574, which means $Spot^{Ask}(€/£) \geq 1.30775574$.

If bank dealer C posts an ask quote $Spot^{Ask}(€/£) = 1.3062$, which is less than 1.30775574, a U.S. trader with $8,000,000 can take action immediately to earn a triangular arbitrage profit. He or she can first sell $8,000,000 to bank dealer B for receiving €7,035,200 (= $8,000,000 × €0.8794/$) and then buy £5,386,005 (= €7,035,200 / €1.3062/£ = £5,386,005.21 ≈ £5,386,005) from bank dealer C by paying €7,035,200 and finally sell £5,386,005 to bank dealer A for receiving $8,009,528 (= £5,386,005 × $1.4871/£ = $8,009,528.04 ≈ $8,009,528). Assume no other trading costs, his or her arbitrage profit is $9,528 (= $8,009,528 – $8,000,000).

[3] If we take the average of bid-ask spreads at the same minute (time) across four days for each high and low volatility periods and then perform Paired t-Test, the conclusion will not change; bid-ask spreads are significantly greater in higher volatility period than those in low volatility periods at 1% level.

If bank dealer C posts an ask quote [$Spot^{Ask}$(€/£)] greater than (or equal to) 1.30775574, following the same steps as described above, a U.S. trader will incur a loss[4] (or zero profit[5]). This is consistent to the above discussion that $Spot^{Ask}$(€/£) ≥ $Spot^{Bid}$(€/£) will eliminate the triangular arbitrage opportunity.

In an Excel assignment file, an instructor can provide students minute-by-minute bid prices for $Spot^{Bid}$($/£) and $Spot^{Bid}$(€/$) and ask prices for $Spot^{Ask}$(€/£) in high and low volatility periods and then ask students to investigate whether triangular arbitrage opportunities increase when the FX volatility becomes higher. One way to collect minute-by-minute $Spot^{Bid}$($/£), $Spot^{Bid}$(€/$), and $Spot^{Ask}$(€/£) data is described as follows.

First, $Spot^{Bid}$($/£) data can be obtained from Tick Data's minute bid data for GBP vs USD currency pair, the real bid price data.

Second, although $Spot^{Bid}$(€/$) data (minute bid data for USD vs EUR currency pair) can be obtained from Tick Data, they are not real bid price data and they are only calculated by the data provider.[6] To find $Spot^{Bid}$(€/$) data, we can base on EUR vs USD currency pair quote data (real quote data with bid and ask prices) obtained from Tick Data and program on the statistical software to only select the closing quote data for each minute of EUR vs USD currency pair and then take the reciprocal of the ask price [$Spot^{Ask}$($/€)]. This is because $Spot^{Bid}$(€/$) = 1 / $Spot^{Ask}$($/€).

Third, $Spot^{Ask}$(€/£) data can be found by taking the reciprocal of $Spot^{Bid}$(£/€) data because $Spot^{Ask}$(€/£) = 1 / $Spot^{Bid}$(£/€). $Spot^{Bid}$(£/€) data can be obtained from Tick Data's minute bid data for EUR vs GBP currency pair, the real bid price data.

We understand that the results of using closing minute data may not be precise because in reality, (1) the arbitrage can be taken before the end of each minute rather than at the end of each minute; (2) the price adjustment can quickly happen at any second of a minute. In addition, there can be other trading costs for exchanging currencies. The purpose of the Excel assignment is to let students practice examining triangular arbitrage opportunities. Using the closing minute data (instead of second data) without considering other trading costs is less complicated for students and meets the purpose of the assignment. The computation results are presented in Table 3.

[4] If bank dealer C posts an ask quote $Spot^{Ask}$(€/£) = 1.3089, which is greater than 1.30775574, a U.S. trader with $8,000,000 who follows the same steps described above will not be able to earn an arbitrage profit and will incur a loss of $6,994 (–$6,994). A U.S. trader first sells $8,000,000 to bank dealer B for receiving €7,035,200 (= $8,000,000 × €0.8794/$) and then buys £5,374,895 (= €7,035,200 / €1.3089/£ = £5,374,894.95 ≈ £5,374,895) from bank dealer C by paying €7,035,200 and finally sells £5,374,895 to bank dealer A for receiving $7,993,006 (= £5,374,895 × $1.4871/£ = $7,993,006.36 ≈ $7,993,006). Assume no other trading costs, his or her arbitrage loss is $6,994 (= $7,993,006 – $8,000,000 = –$6,994).

[5] If bank dealer C posts an ask quote $Spot^{Ask}$(€/£) = 1.30775574 = $Spot^{Bid}$(€/£), a U.S. trader with $8,000,000 who follows the same steps described above will only break even and earn zero arbitrage profit. A U.S. trader first sells $8,000,000 to bank dealer B for receiving €7,035,200 (= $8,000,000 × €0.8794/$) and then buys £5,379,597.875 (= €7,035,200 / €1.30775574/£) from bank dealer C by paying €7,035,200 and finally sells £5,379,597.875 to bank dealer A for receiving $8,000,000 (= £5,379,597.875 × $1.4871/£). Assume no other trading costs, his or her arbitrage profit is $0 (= $8,000,000 – $8,000,000).

[6] According to Client Services of Tick Data, LLC, Tick Data's minute bid data for USD vs EUR currency pair are not actual data; they are calculated by the data provider of Tick Data.

Table 3. Triangular Arbitrage Opportunities

	High Volatility Period	Low Volatility Period	Low Volatility Period
Date (on Thursday)	**06/23/2016**	**05/12/2016**	**07/21/2016**
# of Minutes Available	1439	1440	1440
# of Arbitrage Opportunities	6	4	8
% of Arbitrage Opportunities	0.42%	0.28%	0.56%
Date (on Friday)	**06/24/2016**	**05/13/2016**	**07/22/2016**
# of Minutes Available	1379	1381	1381
# of Arbitrage Opportunities	23	3	7
% of Arbitrage Opportunities	1.67%	0.22%	0.51%
Date (on Monday)	**06/27/2016**	**05/16/2016**	**07/25/2016**
# of Minutes Available	1440	1440	1440
# of Arbitrage Opportunities	11	2	2
% of Arbitrage Opportunities	0.76%	0.14%	0.14%
Date (on Tuesday)	**06/28/2016**	**05/17/2016**	**07/26/2016**
# of Minutes Available	1440	1440	1440
# of Arbitrage Opportunities	16	4	5
% of Arbitrage Opportunities	1.11%	0.28%	0.35%
Total (on Thursday to Tuesday)	**06/23 – 06/28/2016**	**05/12 – 05/17/2016**	**07/21 – 07/26/2016**
# of Minutes Available	5,698	5,701	5,701
# of Arbitrage Opportunities	56	13	22
% of Arbitrage Opportunities	0.98%	0.23%	0.39%

Note: The FX trading is 24 hours, 1440 minutes a day. For each minute, all data for $Spot^{Bid}$(\$/£), $Spot^{Bid}$(€/\$), and $Spot^{Ask}$(€/£) should be available to examine whether there is an arbitrage opportunity. If any one of quotes is not available (missing) at a minute, that minute becomes not available because the arbitrage opportunity cannot be examined at that minute. Due to the missing quote(s) for one or several minute(s), the number of minutes available is less than 1440 on 06/23/2016, 06/24/2016, 05/13/2016, and 07/22/2016.

Table 3 shows that in general, there are very few arbitrage opportunities for each day (less than 1% of trading time for most days). The arbitrage opportunities are the largest on 06/24/2016, the following day after the Brexit vote on 06/23/2016. The arbitrage opportunities per day during the high volatility period are greater than those during the low volatility periods, except for 06/23/2016 (6 times, 0.42% of trading time), compared with 07/21/2016 (8 times, 0.56% of trading time). Overall, there are more arbitrage opportunities (56 times, 0.98% of trading time) in the high volatility period, based on Table 3 results.

CONCLUSION

To assist students better understand the FX market microstructure, an instructor can make an Excel assignment for students to practice. This paper provides two examples regarding the ways of collecting data and making the data set for the Excel assignment. Students can base on the data set of the Excel assignment to examine whether bid-ask spreads are significantly different by calculating the spot FX bid-ask spreads before, around, and after an event and conduct paired t-Test. Students are also able to examine whether an event affects triangular arbitrage opportunities.

AUTHOR BIOGRAPHY

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