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Abstract

Spot foreign exchange market today is the most volatile and liquid of all financial markets in the world. The present paper addresses in detail the efficiency, liquidity and risk seen by a trader, particularly concentrating on the analysis of high frequency data for intraday trading. The main findings of the research include the fact that the market was found to be efficient in weak form, which in particular means that technical analysis cannot be successfully applied to systematically get an above average profit from speculative trades, but fundamental analysis may increase the expected income. Carry trades were not found to be consistently profitable or generating non negative profit. Spot foreign exchange market was proven to be extremely liquid, and its liquidity is being independent from regional trading sessions. We also found no evidence on the spot forex market of hot potato trading that usually follows news announcements. Finally, five different risk measures have shown that the trading based on high frequency data, e.g. minute data, is more risky than the trading using low frequency data, like daily data. The volatility of the market was shown to be increased in the first and the last thirty minutes of the corresponding regional equity trading session(s).

Keywords: foreign exchange market, spot market, market efficiency, expected tail loss, STARR ratio, R-ratio.
JEL Classification: G14, G15.

Introduction

Today the spot forex market is the most liquid and volatile of all financial markets. News announced in the United States are incorporated in London and Hong Kong market quotes within less than ten seconds. The market efficiency characterizes how fast and precise those news are reflected in the exchange rate on the market. Virtually, any financial asset can be bought or sold within seconds during trading sessions. Foreign Exchange market with its 24 hours trading, is considered to be the most liquid of all financial markets. Liquidity influences the attractiveness of an investment and the market efficiency. Finally, the volatility of financial markets is a headache for corporate managers and the source of gain for speculators. It differs greatly between sectors and geographical regions.

The present paper addresses the three major market characteristics, namely efficiency, liquidity and volatility, of the spot foreign exchange market. For each hypothesis, tests on extensive high frequency data are made. The main focus is placed on the application of the derived conclusions to intraday forex trading.

The remainder of the paper is organized as follows. Chapter 1 analyzes the market efficiency. Market liquidity is discussed and tested in chapter 2. Chapter 3 presents different measures of volatility and compares risks associated with different time horizons for trading. The last chapter concludes.

1. Market efficiency

Market efficiency is defined by how fast and how accurately all the relevant information is absorbed by the market, in particular in the price and the traded volume. In 1970, Fama (Fama, 1970) introduced the concept of three forms of the market efficiency: weak, semi-strong and strong. The source of market imperfections and reduced efficiency is multiple: inaccurate public information (Frenkel et al., 2002), actions of more informed participants like Central Banks or market makers.

1.1. Interest rate parity and carry trades. Interest rate parity refers to the relationship between interest rates of two currencies and a corresponding forward exchange rate. Say, i_A and i_B are interest rates of two different currencies, $r_{p.AB}$ and $r_{f.AB}$ are, respectively, the present and the forward exchange rates. Then the relationship $1+i_A = \frac{r_{p.AB}(1+i_B)}{r_{f.AB}}$ has to hold if the market is *efficient*. This relationship is also called *covered interest rate parity*. The market efficiency however has been put in a serious doubt, also in the aspects concerning the interest rates parity (Nguyen, 2000).

An arbitrage attempt is sometimes made through the so called *carry trades*. It consists in borrowing currency generating low interest rate and investing in high yielding currency, assuming the exchange rate does not change over time or at least changes less than necessary to turn a potential profit into a realized loss. To test how profitable carry trades can be, we take an example of trading conditions of one of forex brokers (Fig. 1).

The columns 6 and 7 of the figure below show interest rates charged for overnight positions on the respective currency pair, i.e. the difference in overnight exchange rates. These interest rates are simply meant to reflect the difference between interest rates for each of two exchanged currencies, and thus are meant to be symmetric. In practice, negative rates have higher absolute value which constitutes another part of trading costs.

In attempt to find an evidence if carry trades are susceptible to generate significant positive income, we run hypothetic carry trades for one month on 23 currency pairs, for each month over two years from January 2007 till December 2008.

Dealing Rates (Simple) (22)

Curre...	Sell	Buy	High	Low	Intr S	Intr B	Pip Cost	MMR	Time
EUR/USD	1,3332	1,3335	1,3349	1,3253	0,43	-0,48	0,75	50,00	19:28:15
USD/JPY	117,94	117,97	118,44	117,62	-1,01	0,99	0,64	50,00	19:28:26
GBP/USD	1,9695	1,9699	1,9725	1,9581	-0,05	0,03	0,75	50,00	19:28:33
USD/CHF	1,2147	1,2151	1,2230	1,2116	-0,68	0,64	0,62	50,00	19:28:15
EUR/CHF	1,6197	1,6201	1,6220	1,6169	-0,47	0,45	0,62	50,00	19:28:00
AUD/USD	0,8101	0,8104	0,8109	0,8027	0,17	0,13	0,75	50,00	19:24:52
USD/CAD	1,1620	1,1625	1,1640	1,1592	-0,23	0,21	0,65	50,00	19:28:12
NZD/USD	0,7168	0,7172	0,7184	0,7088	-0,35	0,34	0,75	50,00	19:28:43
EUR/GBP	0,6769	0,6772	0,6778	0,6753	0,40	-0,52	1,48	50,00	19:28:01
EUR/JPY	157,26	157,30	157,41	156,28	-0,87	0,84	0,64	50,00	19:28:46
GBP/JPY	232,31	232,40	232,84	230,83	-1,98	1,87	0,64	50,00	19:28:33
CHF/JPY	97,08	97,12	97,18	96,53	-0,27	0,24	0,64	50,00	19:28:45
GBP/CHF	2,3926	2,3932	2,4011	2,3882	-1,37	1,22	0,62	50,00	19:28:33
EUR/AUD	1,6453	1,6462	1,6525	1,6425	0,68	-0,73	0,61	50,00	19:28:21
EUR/CAD	1,5493	1,5501	1,5516	1,5390	0,14	-0,18	0,65	50,00	19:28:12
AUD/CAD	0,9414	0,9421	0,9430	0,9332	-0,35	0,29	0,65	50,00	19:26:40
AUD/JPY	95,55	95,61	95,73	94,68	-0,95	0,90	0,64	50,00	19:28:37
CAD/JPY	101,47	101,54	101,99	101,28	-0,68	0,64	0,64	50,00	19:27:17
NZD/JPY	84,56	84,62	84,85	83,49	-1,08	1,00	0,64	50,00	19:28:43
GBP/AUD	2,4305	2,4317	2,4418	2,4283	0,33	-0,41	0,61	50,00	19:27:15
AUD/NZD	1,1298	1,1302	1,1377	1,1270	0,23	-0,25	0,54	50,00	19:28:43
EUR/NZD	1,8593	1,8605	1,8765	1,8540	1,05	-1,16	0,54	50,00	19:28:43

Source: www.forexfactory.com, 17th June 2009.

Fig. 1. Overnight rates charged by FXCM broker

We assume each time a position of 1 lot was placed the first day of the month and closed the first day of the next month. Each time the carry position is taken in the direction that generates positive overnight rate. All pip values are converted in USD at the average rate, and thus the generated profit is also expressed in US dollars. The monthly generated income is calculated as

$$Income = Swap\ income + Exchange$$

$$income = 30\ days * Swap\ rate * Pip\ value$$

$$+ Price\ change\ in\ pips * Pip\ value$$

The results of calculations are shown in the table below.

Table 1. Monthly income generated by carry trades

Currency pair	Pip value (USD)	Monthly profits in 2007											
		01/07	02/07	03/07	04/07	05/07	06/07	07/07	08/07	09/07	10/07	11/07	12/07
EURUSD	10.00	-1471	2079	1589	2839	-1761	1009	1519	-351	6569	2079	1839	-371
USDJPY	9.02	1972	-1842	-634	1963	2369	1476	-3898	-2212	-589	782	-3636	836
GBPUSD	10.00	509	-141	659	3049	-1931	2799	2169	-1251	2999	3339	-2531	-6821
USDCHF	8.76	2218	-2057	-287	-384	1719	-200	-1619	834	-3844	-138	-2258	361
EURCHF	8.76	1205	-626	1029	2238	232	574	-854	530	1283	1581	-1765	-57
AUDUSD	10.00	-1221	1129	2259	2039	-211	2269	69	-3361	7309	4359	-4851	-641
USDCAD	9.38	1213	-579	-1639	-3890	-3684	-588	472	-1067	-5832	-4472	5237	-607
NZDUSD	10.00	-1388	1162	1592	2642	-298	3662	-1138	-5828	6082	1372	-988	622
EURGBP	13.64	-1242	1624	887	600	-232	-546	123	396	3165	-82	2401	3206
EURJPY	9.02	507	-377	597	5411	976	2869	-3974	-3623	5718	3013	-3740	579

Table 1 (cont.). Monthly income generated by carry trades

Currency pair	Pip value (USD)	Monthly profits in 2007											
		01/07	02/07	03/07	04/07	05/07	06/07	07/07	08/07	09/07	10/07	11/07	12/07
GBPJPY	9.02	4464	-3750	-657	7151	2534	6150	-5652	-5796	1822	5014	-10115	-5210
CHFJPY	9.02	-314	155	-278	1931	471	1426	-1928	-2550	2716	822	-1161	380
GBPCHF	8.76	5104	-4226	67	2493	1372	2581	-1020	382	-4734	3001	-7292	-6022
EURAUD	8.51	659	284	-2218	-422	-1316	-2507	1450	5339	-5238	-4422	9092	812
EURCAD	9.38	-251	1428	-645	-2428	-6958	68	1925	-1902	-1987	-4716	9101	-1405
AUDCAD	9.38	-359	870	1123	-1044	-3323	1751	485	-4158	2014	-134	363	-1175
AUDJPY	9.02	171	-171	1884	3760	3985	1370	-3210	-5383	7051	5193	-8259	45
CADJPY	9.02	606	-1107	840	5204	5736	1958	-4119	-1098	5601	6070	-9799	1444
NZDJPY	9.02	-126	0	1199	4193	1343	5211	-4391	-7826	5933	1984	-3787	1208
GBPAUD	8.51	4271	-3192	-5073	-1703	-1235	-2392	2075	7190	-14271	-5958	8117	-4996
AUDNZD	7.30	401	7	583	-825	262	-1671	1444	3523	218	2750	-3335	-1204
EURNZD	7.30	0	0	0	0	-354	-5453	3951	10910	-4789	-142	3754	-1215
Currency pair	Pip value (USD)	Monthly profits in 2008											Average
		01/08	02/08	03/08	04/08	05/08	06/08	07/08	08/08	09/08	10/08	11/08	
EURUSD	10.00	2719	3579	5809	389	-2081	1989	-1461	-16341	1759	-13521	989	-26
USDJPY	9.02	-4475	-2221	-3095	3523	2053	818	1864	-751	-372	-8234	-3140	-758
GBPUSD	10.00	179	39	-541	449	-1321	1909	-981	-17151	-2841	-17491	-6941	-1819
USDCHF	8.76	-4317	-3529	-3809	3725	711	-1619	2498	4619	2131	3410	5170	145
EURCHF	8.76	-3964	-2265	-898	4367	521	-1047	2387	-1529	-2799	-9185	5944	-135
AUDUSD	10.00	2009	3759	-1901	2999	1159	439	-1671	-8431	-6201	-12591	-1591	-560
USDCAD	9.38	950	-1498	3877	-1789	-992	2442	312	3680	162	13830	2648	356
NZDUSD	10.00	2042	1392	-1348	-278	232	-1998	-2768	-3228	-2828	-8458	-3868	-592
EURGBP	13.64	1869	2483	4380	-1105	518	423	-382	3643	-2592	300	4571	1061
EURJPY	9.02	-4227	-278	263	4645	1796	2968	1210	-7842	-8491	-21312	-3776	-1178
GBPJPY	9.02	-8781	-4534	-6563	8179	2174	3202	2733	-15408	-6004	-26921	-9953	-2866
CHFJPY	9.02	-124	1264	768	92	831	2445	-810	-3866	-3569	-8392	-5832	-675
GBPCHF	8.76	-8440	-6986	-8028	7723	364	-1642	4044	-7319	995	-11629	960	-1663
EURAUD	8.51	-490	-2303	8402	-5698	-2022	1339	1271	5237	5305	11381	3501	1193
EURCAD	9.38	3820	949	11249	-4201	-2165	5630	-1124	-3234	-5645	3932	2713	181
AUDCAD	9.38	2746	2089	1779	1217	110	2689	-1260	-4946	-6044	-3352	-68	-375
AUDJPY	9.02	-2029	1470	-4616	6329	2633	1118	144	-7628	-7519	-16274	-2984	-996
CADJPY	9.02	-5534	-783	-6832	5538	2571	-1621	1489	-2892	-1928	-16200	-3722	-808
NZDJPY	9.02	-1524	-469	-3760	2777	1479	-1307	-1289	-2678	-3994	-11802	-4797	-975
GBPAUD	8.51	-3992	-7345	3326	-5277	-3226	1097	2331	791	11138	13997	-4017	-363
AUDNZD	7.30	-125	1998	-88	3187	940	2881	1984	-4349	-2839	-3101	4019	290
EURNZD	7.30	-770	1091	8124	-405	-544	6110	4534	-1652	449	5643	11129	1755

In equilibrium, the result of carry trades should be close to zero, i.e. investing in one currency should not produce more income than investing in another. Taking into account trading costs, the result might be expected to be below zero, approximately equal to the encountered trading costs. However, the empirical result varies from several thousands a month of profit to several thousands loss. The average monthly profit is positive for 7 out of 23 currency pairs, and the average of all the trades gives a significant loss. With this quick test, we confirm that we do not find any evidence of profitability or at least stability of carry trades.

1.2. Effect of news announcements on foreign exchange trades. Testing for market efficiency. Official announcements about macro-fundamentals are usually scheduled in advance. Evans and Lyons (Evans, Lyons, 2001 and 2004) address daily data and are paying particular attention to moments of news announcements over a period of six years. They point out that it is difficult to distinguish rational trades following the news announcement, and those that are non rational and have to be rather studied using market psychology.

Contrary to strong form of market efficiency, semi-strong and weak forms of this hypothesis are less restrictive. Semi-strong form claims that all *public* information is incorporated in prices, which exclude any privately known information. In other words, if a market is proved to be efficient in semi-strong form, neither fundamental nor technical analysis can consistently produce abnormal returns. The weak form of market efficiency states that all past prices are reflected in the today's price on the market. This

basically means that is it not possible to get any significant advantage on the market by analyzing pastprices only, as it is done in the case of technical analysis. However, fundamental analysis can be successfully applied.

Tools used to test market efficiency are dependent on the form of efficiency to be tested. Weak form may be detected using unit root tests. Semi-strong form is analyzed using cointegration, Granger causality and variance decomposition analysis. To define whether the foreign exchange market is efficient in semi-strong form, we are going to test:

- if the spot exchange rate behaves as a random walk; and,
- if there is cointegration among a set of spot rates.

If this analysis does not provide us with a positive answer, we will run a unit root test to check if the foreign exchange market is efficient in a weak form over short period of time.

1.3. Methodology. To test if there is cointegration among spot rates, we do a two step analysis:

1. We find the order of integration of the variables, i.e. the number of times is differentiated before becoming stationary. For this, we use the Augmented Dickey-Fuller (ADF) test, which we expect to be confirmed by Phillips-Perron (PP) test. The reason of this step is that the test for cointegration should be done only among variables with the same degree of integration.
2. We apply Engle and Granger method to define if variables are cointegrated. In this method, one variable is regressed on the other, and we test if the residuals are stationary. Again, the Augmented Dickey-Fuller and Phillips-Perron tests are used to test for stationarity.

1.4. Data. The analysis is first run on the minute-by-minute exchange rates on a set of currency pairs for the period from 1st March 2009 until 31st May 2009. Because of the extensive second step of the analysis, our attention is restricted to only the exchange rates of USD vs. major currencies: EUR, GBP, CHF, JPY, CAD, AUD, NZD.

1.5. Results. The results of the Augmented Dickey-Fuller and the Phillips-Perron tests are in the table below. At this first step, if there is a unit root of a series, it is considered to be non stationary, and it is differentiated once again.

The procedure is repeated until the p-value of at least one of two unit root tests is below 5%. The table presents the tests statistics along with p-values, as well as the number of times the series was differentiated until became stationary.

Table 2. Statistics and p-values of the Augmented Dickey-Fuller and the Phillips-Perron unit root tests, minute data

Currency pair	Times diff.	ADF (p-value)	PP (p-value)
USDCHF	1	-45.7 (0.01)	-217 (0.01)
EURUSD	1	-45.3 (0.01)	-206 (0.01)
GBPUSD	1	-44.1 (0.01)	-192 (0.01)
USDJPY	1	-46.1 (0.01)	-214 (0.01)
USDCAD	1	-45.4 (0.01)	-209 (0.01)
AUDUSD	1	-44.4 (0.01)	-204 (0.01)
NZDUSD	1	-44.7 (0.01)	-224 (0.01)

As seen in Table 2, all the series became stationary after one differentiating. Thus, the Engle and Granger method can be run on the second step, and Table 3 presents, for each pair of exchange rates, the statistics and the p-value of the Augmented Dickey-Fuller and Phillips-Perron tests for residuals of regression of one series of exchange rates on another.

Table 3. Results of the Engle and Granger method applied to daily exchange rates: statistics and p-values of ADF and PP tests, for residuals of the regression of price series of one currency pair against another, minute data

	USDCHF	EURUSD	GBPUSD	USDJPY	USDCAD	AUDUSD	NZDUSD
USDCHF	-4.84 (0.01), -304 (0.01)	-2.27 (0.46), -2.35(0.43)	-2.85 (0.21), -2.96 (0.17)	-2.5 (0.34), -2.54 (0.35)	-2.85 (0.21), -3.06 (0.12)	-2.15 (0.51), -2.25 (0.47)	-2.12 (0.53), -2.20 (0.50)
EURUSD			-2.78 (0.25), -2.83 (0.23)	-2.61 (0.32), -2.57 (0.33)	-2.44 (0.39), -2.54 (0.35)	-1.62 (0.74), -1.75 (0.68)	-2.07 (0.55), -2.18 (0.50)
GBPUSD				-2.39 (0.41), -2.42 (0.40)	-3.41 (0.05), -3.72 (0.02)	-3.19 (0.09), -3.26 (0.08)	-2.80 (0.24), -2.89 (0.20)
USDJPY					-2.86 (0.21), -2.91 (0.19)	-2.64 (0.30), -2.55 (0.34)	-2.16 (0.51), -2.06 (0.55)
USDCAD						-2.34 (0.43), -2.56 (0.34)	-2.15 (0.51), -2.22 (0.49)
AUDUSD							-2.00 (0.58), -2.23 (0.48)

The results obtained in Table 3 are consistent with previous studies: the market is not efficient in a semi-strong form. This time the proof of it has been given for the foreign exchange market, on

the minute-by-minute exchange rates of the major currency pairs.

We can finally check if the market is efficient in a weak form. As was seen during the conducted analysis using high frequency minute data, for every series, the null hypothesis of unit root could not be rejected. Thus, it is assumed the forex market displays weak form of efficiency over short term.

2. Market liquidity

Market liquidity characterizes how easy and fast the assets can be exchanged, moved, bought or sold, without effecting price and incurring significant costs. Forex market in general is extremely liquid and it operates the daily volume of 3.2 trillion USD (as of April 2007, Bank for International Settlements, 2007), 24 hours a day, actively five days a week and even with some transactions over the weekend.

2.1. Measures of liquidity. Potential measures of liquidity include:

1. Frequency with which transactions take place – how often assets are bought and sold.
2. Probability that the next transaction will be executed at the same price as the previous one – a measure of both the frequency of transactions and the possibility to buy or sell at the current market price.
3. How much trades influence the price. On a less liquid market trades are more susceptible to move the market price.

Market makers contribute greatly to the liquidity of the market, by translating the illiquidity of an asset into cost, usually in the form of the spread. The figure below shows an example of trading conditions of one of foreign exchange market makers, offering trades on seventy currency pairs.

Symbol	Spread	Limit & Stop Orders	Max. Per Trade (Streamline)
EURUSD	2	5	200
USDJPY	2	5	100
AUDUSD	2	5	50
GBPUSD	3	5	50
USDCHF	3	5	100
USDCAD	3	5	50
NZDUSD	4	5	50

Crosses

Symbol	Spread	Limit & Stop Orders	Max. Per Trade (Streamline)
EURGBP	2	5	100
EURCHF	2	5	100
EURJPY	3	5	50
CADJPY	4	5	50
CHFJPY	4	5	50
AUDJPY	5	5	50
GBPCHF	6	5	50
NZDJPY	6	5	20
EURAUD	8	5	50
EURCAD	6	5	20
AUDCHF	7	5	30
NZDCAD	7	5	20
EURDKK	7	5	50
AUDCAD	7	5	20
GBPCAD	8	5	20
GBPAUD	8	5	20
CADCHF	8	5	20
NZDCHF	8	5	20
GBPJPY	7	5	50
NOKSEK	10	5	50
EURNZD	7-20	5	20
AUDNZD	10-20	5	20
EURTRY	18-35	5	20
EURNOK	30	10	50
EURSEK	30	10	50

Symbol	Spread	Limit & Stop Orders	Max. Per Trade (Streamline)
CADSGD	7	5	10
SGDJPY	7	5	10
USDHKD	8	5	50
USDSGD	7	5	30
CHFSGD	10	5	10
EURSGD	10	5	20
NOKJPY	10	5	50
SEKJPY	13	5	50
NZDSGD	13	5	10
USDTRY	13-25	5	20
TRYJPY	13	5	20
GBPNZD	18	5	50
GBPSGD	15	5	10
USDDKK	15	5	20
EURHKD	30	10	50
USDNOK	30	10	20
NZDDKK	30	10	20
CHFNOK	30	10	30
CHFPLN	30	10	30
EURCZK	30	10	30
EURHUF	30	10	30
USDCZK	30	10	30
USDPLN	30	10	30
USDHUF	30	10	20
SGDHKD	30	10	30
EURPLN	30	10	50
USDSEK	30	10	20
USDMXN	55	15	30
HKDJPY	55	15	30
GBPPLN	55	15	20
GBPNOK	75	15	10
GBPSEK	75	15	10
NZDSEK	75	15	10
GBPTRY	28-45	10	50
GBPDKK	35	15	50
GBPHUF	45	15	10
EURZAR	125	20	10
USDZAR	125	20	10

Source: www.migfx.com, 20th June 2009.

Fig. 2. Spreads on curency pairs of MIG Investments SA

As it can be observed, majors have a tight spread of two to three basic points, while exotic currency pairs, traded with a spread higher than 100 points. Translating spread into money, it means if one buys and immediately sells one lot of EURUSD, i.e. 100 000 EUR, with no price change in the meanwhile, he loses 20 USD as trading costs, in the form of the spread. The same operation on USDZAR will cost him 1250 USD!

2.2. Time-varying liquidity. The trading on the foreign exchange market is not uniform over time. Central Banks interventions decrease forex market liquidity and increase costs borne by traders (Pasquariello, 2002). Evans, Lyons (Evans, Lyons, 2004) investigate if trades have more influence on the price around the moments of news announcements, and come to a positive conclusion.

During the day, the level of trading activity is variable. If we schematically split the 24-hour period of trade into "Japanese", "European" and "American" sessions, corresponding to business hours in each respective part of the world, we can expect significant movements of currencies in periods of business hours of its home region. For example, the EURUSD currency pair would most move during the European and American session, but very little during Japanese business hours.

ECONOMIC EVENTS

May 31, 2009 - Jun 06, 2009

Displaying: All Currencies Impact: High, Medium, Low

31 SUNDAY	01 MONDAY	02 TUESDAY	03 WEDNESDAY	04 THURSDAY	05 FRIDAY	06 SATURDAY

18 of 18 events Print: PDF | Excel Impact: High Medium Low

GMT	currency	event	actual	forecast	previous
01:30	AUD	AiG Construction Index - May	46.9		36.5
07:15	CHF	Consumer Price Index (MoM) - May	0.20%	0.20%	0.90%
07:15	CHF	Consumer Price Index (YoY) - May	-1.00%	-0.90%	-0.30%
08:30	GBP	Producer Price Index Input n.s.a (MoM) - May	0.40%	0.80%	-1.00%
08:30	GBP	Producer Price Index Input n.s.a (YoY) - May	-9.40%	-8.30%	-5.00%
08:30	GBP	Producer Price Index Output n.s.a (MoM) - May	0.40%	0.40%	0.60%
08:30	GBP	Producer Price Index Output n.s.a (YoY) - May	-0.30%	-0.40%	1.20%
08:30	GBP	Producer Price Index Output Core n.s.a (MoM) - May	0.20%	0.20%	0.40%
08:30	GBP	Producer Price Index Output Core n.s.a (YoY) - May	1.20%	1.10%	2.40%
11:00	CAD	Unemployment Rate - May	8.40%	8.30%	8.00%
11:00	CAD	Net Change in Employment - May	-41.8K	-42.5K	35.9K
12:30	USD	Change in Non-farm Payrolls - May	-345K	-530K	-539K
12:30	USD	Unemployment Rate - May	9.40%	9.20%	8.90%
12:30	USD	Changes in Manufacturing Payrolls - May	-156K	-150K	-149K
12:30	USD	Average Hourly Earnings (MoM) - May	0.10%	0.20%	0.10%
12:30	USD	Average Hourly Earnings (YoY) - May	3.10%	3.00%	3.20%
12:30	USD	Average Weekly Hours - May	33.1	33.2	33.2
19:00	USD	Consumer Credit - Apr.	-15.7B	-$6.0B	-$11.1B

Soure: www.fx360.com/calendar, 22nd June 2009.

Fig. 3. Calendar of news announcements affecting the foreign exchange market

Figure 3 shows an example of forex news announcements calendar. The announcements of medium to high importance are susceptible to temporarily affect market operations. To test it, we will compare the market liquidity between the time around a news announcement and all the other trad-

ing time. We analyze the announcements of medium and high importance as indicated and scheduled on publicly available calendars, e.g. www.fx360.com or www.dailyfx.com. Following statistics will be analyzed:

- percentage of trades that were made at the same price as the previous trade, for evaluating regional sessions activity;
- time between trader's request and the moment when the transaction is completed, for evaluating the impact of news announcements.

2.3. Percentage of trades executed at the same price. We analyze the order flow on 70 currency pairs over three months from 1st March 2009 till 31st May 2009. Each order is decomposed into two transactions – opening and closing. We additionally consider that the currency may be more volatile as the equity market trading session is opened and as news about the relative macro fundamentals are arriving. We account for the next trading sessions:

1. Japanese session (Tokyo Exchange): 9.00am till 3.00pm JST (GMT+9), for JPY, AUD, NZD, HKD, SGD;
2. European session (Frankfurt Exchange): 9.00am till 5.30pm CET (GMT + 1)/ CEST (GMT + 2), for EUR, CHF, GBP, DKK, NOK, SEK, PLN, HUF, CZK, TRY, ZAR;
3. American session (New York Stock Exchange): 9.00am till 4.00pm EST (GMT-5)/ EDT (GMT-4), for USD, CAD, MXN.

For each currency pair, we calculate the number of transactions for each quadrant as shown in Table 4.

Table 4. Classification of counted transactions

	Regional session opened	Regional session closed
Execution at same price as previous trade		
Execution at different price from previous trade		

After the analysis and in order to have meaningful comparison, only those currency pairs were kept, for which there was on the average at least one transaction per hour for the whole three months of analysis. The statistics is presented in Table 5.

Table 5. Part of transactions executed at the same price as the previous trade depending if the regional sessions are opened for either of currencies

Currency pair	Same price, session(s) opened, %	Same price, session(s) closed, %
AUDCAD	42.6	46.9
AUDJPY	39.6	38.3
AUDNZD	10.7	21.4
AUDUSD	37.5	29.4
CADCHF	69.9	56.6
CADJPY	37.5	31.8
CADSGD	69.2	55.7
CHFJPY	41.0	42.0
CHFSGD	62.5	58.2
EURAUD	15.6	17.3
EURCAD	75.7	72.8
EURCHF	44.3	51.2
EURGBP	57.6	48.3
EURJPY	31.5	41.9
EURNZD	33.3	16.3
EURTRY	10.6	12.6
EURUSD	40.6	46.2
GBPAUD	14.5	12.7
GBPCAD	61.0	59.2
GBPCHF	25.4	38.1
GBPJPY	22.2	33.6
GBPUSD	37.0	35.9
NZDCAD	1.0	3.0
NZDUSD	40.3	25.9
USDCAD	30.2	33.6
USDCHF	67.5	51.5
USDJPY	44.2	51.8
USDTRY	27.3	23.7

Observing the results of calculations, we do not find any signs of an increased percentage of trades executed at the same price as the previous one. The difference between the values calculated for periods when regional sessions are opened and when they are closed, differs very slightly. For some currency pairs, like AUDCAD, AUDNZD, EURJPY, USDCAD, the relationship is even shown to be and inverse.

2.4. Time between trader's request and the completion of a transaction. The same transactions flow is analyzed under a magnifying glass, considering each transactions as a sequence of electronic information exchanges. At every occurrence, we measure the total time elapsed between the moment the trader generates the initial request and the moment the position is placed on the market. We compare the average time required 3 minutes prior and 10 minutes after major and medium news announcements, and all other trading time. The results are shown in Table 6.

Table 6. Time required to complete a market transaction

	Average time, s	Standard deviation
News time (major news)	3.24	4.76
News time (medium news)	3.21	4.65
Non news time	3.21	4.47

It is a common practice that small orders are typically processed automatically, while important trades can be verified by a dealer before they are

being approved. If we assume that trading system can automatically handle any volume the market generated at any conditions without changing the processing time, we narrow the analysis to positions processed after a dealer's approval. The results are presented in Table 7.

Table 7. Time required to complete a market transaction (manual order processing only)

	Average time, s	Standard deviation
News time (major news)	4.62	8.35
News time (medium news)	4.60	8.10
Non news time	4.48	7.68

The results above do not witness for any significant difference between the processing time. We attempt to make only the distinction between major news and no news, as well as restrict the definition of news time to 1 minute prior and 5 minutes after the news announcement. The results are in Table 8.

Table 8. Time required to complete a market transaction (important news only)

	Average time, s	Standard deviation
All transactions		
News time (major news)	3.23	4.69
Non news time	3.21	4.48
Manual processing only		
News time (major news)	4.71	8.32
Non news time	4.49	7.70

From the results above, we conclude that the orders processing time as a measure of forex market liquidity does not change in the period of news announcements.

2.5. Hot potato trading. Evans and Lyons (Evans, Lyons, 2001) analyze the market liquidity using the orders flow. A particular attention is paid to the "hot potato" trading, when positions are passed many times between traders and dealers, for risk management purposes. Hot potato trading generates increases in the number of transactions, i.e. a certain volume of demand and supply. On the other hand, repetitive transactions in both directions are susceptible to compensate themselves, thus having the resulting signed order flow to remain the same.

The model is described by two equations below:

$$\Delta P_t = (\beta_1 + \beta_2 A_t)x_t - \beta_3 \Delta P_{t-1} + \eta_t^p, \quad (1)$$

$$\Delta x_t = \beta_4 x_{t-1} + \beta_5 \Delta P_{t-1} + \eta_t^p, \quad (2)$$

where ΔP_t is the price change in the moment t, x_t is the order flow in the moment t.

$$\eta_t^p = \beta_6 \Delta R_t, \quad (3)$$

$$\eta_t^x = (\beta_7 + \beta_8 A_t)x_t^{AGG}, \quad (4)$$

$$\beta_i > 0, i = 1...8,$$

ΔR_t is the payoff increment in the moment t, x_t^{AGG} is aggregated order flow in the moment t, A_t indicates a proximity of news announcements.

Evans and Lyons (Evans, Lyons, 2005) found evidence of a clear impact of news announcements on market liquidity, as well as some evidence of hot potato trading using hourly data. To test for presence of hot potato trading activity on minute data on forex, we are going to estimate the model for the major currency pairs using unsigned orders flow. A dummy variable A_t takes the value of one minute prior and ten minutes after major and medium news announcements, otherwise. The β_2, its p-value and R^2 of the model are presented in Table 9.

Table 9. A_t, p-value and R^2 of the estimated hot potato trading model, minute data

Currency pair	β_2 (p-value)	R^2
EURUSD	0.0 (0.122)	13.53%
USDCHF	0.0 (0.002)	10.26%
GBPUSD	0.0 (0.137)	18.34%
USDJPY	0.0 (0.729)	11.02%
USDCAD	0.0 (0.358)	10.83%
AUDUSD	0.0 (0.201)	14.53%
NZDUSD	0.0 (0.546)	9.35%

All the coefficients differentiating between news announcements time, i.e. expected time of hot potato trading, and all the other time, are at zero. We thus find no evidence of hot potato trading on the foreign exchange market.

3. Volatility and risk

Market volatility is a characteristic that describes how often and how much the market, in particular the price, changes. Market volatility is perceived differently by different market participants: it is desirable for active speculators, but tends to be avoided by long-term investors.

3.1. Measures of volatility and risk. Volatility is traditionally measured using basic statistical tools, like variance and standard deviation. According to Mandelbrot (Mandelbrot, Hudson, 2004, p. 48), this measure only reflects one part of the real market risk, "benign risk". The remaining "wild risk" is often neglected by researches, unless they use stable Pareto distributions. An alternative measure of volatility could be the number of price ticks arriving per unit of time – useful information for speculators.

Value-at-Risk, or VaR, at the $100(1-\alpha)\%$ confidence level is generally defined by the upper 100α percentile of the loss distribution and is denoted as $VaR_{\alpha}(Z)$, where Z is the random variable of loss. The VaR is a rather simplistic measure that only gives the level of loss. The investor does not know anything from VaR about the potential loss beyond this limit. An investment with VaR of 10 000 USD is not necessarily less risky than that with the VaR at 20 000 USD, if its potential maximum loss is 100 000 USD vs. 50 000 USD of the second asset. This type of risk if often referred to as tail risk.

An extension of the VaR definition is the Expected Shortfall measure, otherwise called Expected Tail Loss. While using this measure, one assumes the loss is already beyond the VaR level. The Expected Shortfall measures the expected loss under these conditions, i.e. is the conditional expectation of loss, when the loss exceeds the VaR level (Arztner et al., 2007, 2009). In other words, it calculates how severe the average loss is, if VaR is exceeded (Rachev et al., 2006):

$$ETL_{\alpha 100\%}(r) = E(l > VaR_{(1-\alpha)100\%}(r)), \quad (5)$$

where r is the return given over time horizon, $l = -r$ is the loss.

$ETL_{\alpha 100\%}(r)$ is also denoted $CVaR_{(1-\alpha)100\%}(r)$ meaning conditional VaR.

Three ratios are commonly used to evaluate the risk of an investment:

1. Sharpe Ratio (Sharpe, 1966) is a measure of risk-adjusted performance of an investment asset or a trading strategy. It is defined as:
$$S = \frac{E(R - R_f)}{\sigma}. \quad (6)$$
The major shortcoming of this ratio is the underlying assumption of a normal distribution of residuals.
2. Stable-Tail Adjusted Return Ratio (STARR) (Rachev, 2006) is the ratio between expected return and its conditional value at risk:
$$\rho = \frac{E(r - r_f)}{CVaR_{(1-\alpha)100\%}(r - r_f)} = STARR_{(1-\alpha)100\%}. \quad (7)$$
3. Rachev ratio (R-ratio) (Rachev et al., 2007) with parameters α and β is defined as:
$$\rho = \frac{ETL_{\alpha 100\%(r-r_f)}}{ETL_{\beta 100\%(r-r_f)}} = R - ratio(\alpha, \beta), \quad (8)$$
where α and β are in $[0,1]$. The idea of this ratio is to maximize the level of return and get insurance for the maximum loss. It, thus, out of three presented ratios, provides the most flexibility in terms of underlying distribution and desired levels of confidence.

For both STARR and R-ratio, a lower absolute value negative result indicates a higher risk. The table below compares the risk of trading different currencies, on minute and daily data for the period from 1st March 2009 till 31st May 2009. ETL is calculated based on the assumption that the errors follow an α-stable distribution.

Table 10. Volatility evaluated on daily and minute data: Sharpe ratio, $VaR_{10\%}$, $ETL_{10\%}$, $STARR_{90\%}$, $R - ratio_{0.1,0.8}$

Currency pair	Daily data					Minute data				
	Sharpe ratio	VaR (10%)	ETL (10%)	STARR (90%)	R (0.1,0.8)	Sharpe ratio	VaR (10%)	ETL (10%)	STARR (90%)	R (0.1,0.8)
AUDCAD	0.0015	0.8302	-0.0800	-1.1155	-8.5090	0.0445	0.8079	-0.0785	-1.1150	-8.5512
AUDCHF	0.0015	0.6884	0.0137	-1.1913	50.9403	0.0167	0.6630	0.0359	-1.2166	19.7107
AUDJPY	0.0000	-9.0034	1.0615	-0.7443	-0.9814	0.0000	-8.4068	1.0241	-0.7589	-1.0888
AUDNZD	0.0010	1.1733	-0.0628	-1.1403	-16.486	0.0235	1.1674	-0.0606	-1.1396	-17.034
AUDUSD	0.0016	0.6591	-0.0637	-1.1242	-9.1601	0.0088	-7.5920	1.0057	0.5165	1.8564
CADCHF	0.0013	0.8034	-0.0029	-1.1654	-270.04	0.0435	0.8101	0.0189	-1.1971	42.2920
CADJPY	0.0000	-5.6208	0.9071	-1.4413	4.8332	0.0000	-3.9164	0.8565	-1.3543	5.3709
CHFJPY	0.0000	-3.5578	0.9135	-1.1781	9.3900	0.0000	-8.3454	1.0974	-1.2331	7.1522
CHFSGD	0.0009	0.3692	0.3481	-1.6275	3.8032	0.1338	0.1529	0.4332	-1.8940	3.3520
EURAUD	0.0006	1.7325	-0.1430	-1.1726	-11.181	0.0082	1.7489	-0.1398	-1.1753	-11.457
EURCAD	0.0007	1.5410	-0.0250	-1.2415	-58.668	0.0160	1.5743	-0.0973	-1.1951	-14.518
EURCHF	0.0009	1.4886	-0.1413	-1.1141	-8.5906	0.1075	1.4941	-0.1427	-1.1157	-8.5254
EURGBP	0.0014	0.8767	-0.0652	-1.1830	-11.923	0.0236	0.8786	-0.0442	-1.2259	-18.251
EURJPY	0.0000	-4.3413	0.8341	-1.3445	5.6189	0.0000	-5.5108	0.8959	-1.4584	4.7270
EURNZD	0.0005	2.2083	-0.2169	-1.1198	-8.6620	0.0064	0.0103	0.5711	-1.5590	4.4859
EURSGD	0.0006	1.9573	-0.0753	-1.2119	-23.420	0.0733	1.8094	-0.0624	-1.1453	-26.111

Table 10 (cont.). Volatility evaluated on daily and minute data: Sharpe ratio, $VaR_{10\%}$, $ETL_{10\%}$, $STARR_{90\%}$, $R-ratio_{0.1,0.8}$

Currency pair	Daily data					Minute data				
	Sharpe ratio	VaR (10%)	ETL (10%)	STARR (90%)	R (0.1,0.8)	Sharpe ratio	VaR (10%)	ETL (10%)	STARR (90%)	R (0.1,0.8)
EURUSD	0.0009	-6.2869	0.9386	4.3122	2.1823	0.0220	1.0741	-0.1048	-1.1208	-8.8516
GBPCHF	0.0008	-0.3937	0.5056	-1.7512	3.3735	0.0242	-0.5833	0.5545	-1.8589	3.2106
GBPJPY	0.0000	-9.2981	1.0793	-0.7307	-0.8056	0.0000	-9.5146	1.0922	-0.7231	-0.7294
GBPUSD	0.0008	12.5331	-	-	-	0.0119	1.5575	-0.1555	-1.1257	-8.5345
NZDCAD	0.0018	0.6622	-0.0556	-1.1290	-10.132	0.0531	0.6810	-0.0677	-1.1180	-8.2825
NZDCHF	0.0019	0.6152	-0.0592	-1.1199	-8.9276	0.0747	0.5869	0.0174	-1.2117	32.6655
NZDJPY	0.0000	-4.1983	0.6461	0.5975	1.8360	0.0000	-6.3214	0.8338	-0.7178	-0.5423
NZDUSD	0.0020	0.5309	-0.0454	-1.1315	-10.255	0.0113	0.5257	-0.0413	-1.1327	-11.326
USDCAD	0.0010	-1.2897	0.5613	-3.2237	2.4629	0.0118	-1.1467	0.5521	-2.9630	2.5018
USDCHF	0.0011	1.0003	-0.0949	-1.1158	-8.9029	0.0400	1.1056	-0.1063	-1.1195	-8.6786
USDJPY	0.0000	-8.1169	1.0273	-0.5349	0.4751	0.0000	-7.8630	1.0093	-0.6059	0.1148
USDZAR	0.0001	1.6547	0.7582	-1.1781	9.7922	0.0005	6.2553	0.5250	-1.1665	-26.586

As can be observed, the risk increases as one uses higher frequency data. This is an important remark, because it shows that the foreign exchange market does not display fractal properties as suggested by Mandelbrot (Mandelbrot, 2004), even if the charts are visually very similar. Low frequency daily data and high frequency minute data on the same underlying currency pair do not have the same properties. The practical conclusion is, however, as expected: the trading on high frequency data is more risky than using longer-term information.

3.2. Time-varying volatility. On the equity market, volatility is known to follow a U-shape (Lyden, 2007), as the intensity and the volume of trades are higher towards the beginning and the end of the trading day. On the 24-hour forex market, however, there is no formal trading day, but rather regional sessions that correspond to the trading day on the equity market of the respective region: Japanese, European and American.

According to the Glosten-Milgrom-Harris model (Glosten et al., 1988), changes in observed transaction prices have permanent part π, affecting future trades, and temporary component τ which reflects the influence on the current trade only. The size of effects equals q; Q_t indicates whether the trader takes a long or a short position. The exogenous term ε_t is the non explained part of the price variation. The model is expressed by the following equation:

$$\Delta p_t = \pi(q_t)Q_t + \tau(q_t)\Delta_t + \varepsilon_t. \quad (9)$$

Lyden (Lyden, 2007) finds evidence that the temporary impact is higher during the first half-hour of the trading day.

We modify the initial equation of the model. Instead of the price change, we evaluate the number of ticks per unit of time T_t as a measure of price volatility. As an indicator of specific period of time, we introduce the variable S_t having the value of:

$$S_t = \begin{cases} 0, \text{ if no session is active}, \\ 2, \text{ if beginning or end of} \\ \quad \text{any regional trading session}, \\ 1, \text{ otherwise}. \end{cases} \quad (10)$$

We thus estimate the equation:

$$T_t = \pi(q_t) + \tau(q_t)S_t + \varepsilon_t, \quad (11)$$

where $\pi(q_t)$ and $\tau(q_t)$ are assumed to be constants. The model is estimated on the minute data. The estimated values of the coefficient τ along with its p-value for major currency pairs are presented in the table below. The results for cross and exotic currency pairs are of the same order.

Table 11. τ and p-value for the Glosten-Milgrom-Harris model

Currency pair	τ	p-value
EURUSD	4.41	0.00
USDCHF	4.18	0.00
GBPUSD	5.71	0.00
USDJPY	0.63	0.14
USDCAD	1.63	0.00
AUDUSD	0.15	0.55
NZDUSD	0.15	0.32

For four currency pairs out of seven, there is a non negligible evidence of an increased volatility during

the first and the last 30 minutes of either regional equity trading session.

Conclusion

The present research studied crucial properties of the spot foreign exchange market over the short term such as efficiency, liquidity and volatility. In particular, it was found on minute data that the forex market is efficient in weak form. Foreign exchange is also being extremely liquid, and its liquidity is not affected by regional equity trading sessions and news announcements. Finally, the forex market is exceptionally volatile, especially on the high frequency data. Additionally, it was noted that forex data, in spite of apparent fractals pattern, do not have same properties at different scales, in particular in terms of market volatility. The main conclusion for short-term intraday trading is that investors should be particularly cautious and use specified models only, as traditional equity and long-term forex models are not appropriate. In terms of future research, the intraday spot forex trading is definitely a vast domain that is still to be explored and new adequate models are still to come.

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