Do Exchange Rates Follow Random Walks? Evidence from the Currency Market in New York

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Abstract

This paper employs non-parametric methods to study the efficiency of four major exchange rates ($/British pound, $/euro, $/Swiss franc, and $/yen), using daily data over the period 1999-2011. Our major findings are as follows. First, each exchange rate is not normally distributed. Second, each exchange rate does not follow a random walk in the runs up and down test. Third, each exchange rate does not follow a random walk in the runs above and below a central point test. We suggest that different time zones of two currencies in an exchange rate, government interventions, and exchange rate overshooting or undershooting may result in market inefficiency. If the transaction cost is small and the foreign exchange market is not weak-form efficient, investors may be able to explore profitable opportunities. Overall, our new evidence suggests that these four exchange rates do not follow a random walk. This result is not consistent with the literature.

I. Introduction

The foreign exchange market plays an important role in currency conversion, hedging, arbitrage, and speculation. Because the cash flows of multinational companies are normally denominated in various currencies, these companies use the foreign exchange market to manage currency risk. When exchange rates change, the performance of these companies can be greatly affected. An efficient foreign exchange market can benefit all participants by facilitating the transactions between buyers and sellers, generating continuous prices, and producing fair prices. Naturally, market participants are concerned with the efficiency of the foreign exchange market.

As suggested by Fama (1970), the efficient market hypothesis (EMH) states that if there is no friction, securities prices in efficient markets fully reflect available information. This hypothesis implies that successive prices (or, price changes) are independent. He further classifies efficient markets into three forms in terms of the information set. First, if future prices do not depend on historical prices (i.e., the information set), then the market is weak-form efficient. Second, when securities prices fully incorporate all publicly available information (a larger information set), the market is semi-strong form efficient. Third, when the information set contains public and private information (an even larger information set), which is fully reflected in securities prices, the market is strong-form efficient.

Since market efficiency influences many different sub-fields of finance and can determine whether or not a market is well developed, the efficient market hypothesis (EMH) is a critical element of finance theory. Many scholars and practitioners have tested different forms of efficiency and tried to draw conclusions and implications from test results. Because it is more complicated to test the semi-strong form and strong form market efficiency, most existing papers investigate the weak-form efficiency, using stock price data. With some exceptions, the stock markets in developed countries (e.g., the U.S.) tend to be weak-form efficient, but the stock

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markets in many non-developed markets (e.g., emerging-market countries) are not. If financial markets are not efficient, it implies that there may exist arbitrage opportunities for investors.

This paper is different from most of previous studies on market efficiency in five important aspects. First, while most previous papers research the topic using stock price data, we employ the exchange rate data. The foreign exchange market is different from the stock market in that the former is less regulated and is not used for raising funds. Second, unlike many previous studies that use weekly or monthly data, we use the daily data. Third, we use non-parametric methods to examine the market efficiency of exchange rates to solve the problem of non-normal distributions of the data. Fourth, we focus on the four major exchange rates, whose currencies are the most traded, according to the Bank of International Settlements (BIS) surveys in various years. Finally, as compared with Liu and He (1991), our paper uses more recent data, including a new exchange rate ($/euro) that became available in 1999.

After examining the four daily exchange rates ($/British pound, $/euro, $/Swiss franc, and $/yen) over the period 1999-2011, our major findings are as follows. First, each of the four exchange rates is not normally distributed. Second, each exchange rate does not follow a random walk in the runs up and down test. Third, each exchange rate does not follow a random walk in the runs above and below a central point test. We suggest that different time zones of two financial markets, government interventions, and exchange rate overshooting or undershooting may play a role in market inefficiency.

The remainder of this paper is organized as follows. Section II briefly discusses the related literature. In Section III, we describe the data and methodology. Section IV presents and discusses empirical results. We summarize and conclude in Section V.

II. Literature Review

The efficient-market hypothesis (EMH) maintains that financial markets are informationally efficient with securities prices fully reflecting all available information. As a result, investors cannot consistently outperform the overall market on a risk-adjusted basis.

Although the concept of market efficiency already existed some four hundred years ago, Fama (1965) is the first to formally define what an efficient market is. Also, Samuelson (1965) is, among the first, to provide the formal mathematical model for efficient markets by focusing on the concept of a Martingale, which is a stochastic process that shows the conditional expectation of the next price is the current price.

Because market efficiency is a very important topic in finance and economics, many papers have studied this topic in different ways, in terms of the type of market (stock vs. non-stock), status of market (developed vs. non-developed), data frequency (weekly vs. non-weekly), data type (individual stocks vs. market indexes), methodology, and so on. Here, we'll briefly review three lines of research.

The first line of research focuses on the market efficiency of developed markets. Fama (1965) finds that the first-order autocorrelations of daily returns are positive for 23 of the 30

Dow Jones Industrial Average (DJIA) stocks in the U.S. and the autocorrelation coefficient is more than two standard errors from zero for 11 of the same 30 stocks. Lo and MacKinlay (1988) group NYSE-listed stocks into different sizes of portfolios and find that weekly returns on these portfolios show reliable positive autocorrelation over the period 1962-1985. In particular, the autocorrelation is stronger for portfolios of small stocks. By reviewing 280 papers studying western European markets, Hawawini and Michel (1984) conclude that the stock prices in these markets follow a random walk. Groenewold (1997) finds that the stock markets in Australia and New Zealand are weak-form efficient over the period 1975-1992. In general, most empirical studies on developed markets show that future prices do not depend on the past prices, supporting the weak-form efficiency of the EMH.

The second line of research focuses on the market efficiency of non-developed markets. Butler and Malaikah (1992) examine weak-form efficiency in the publicly traded stocks of Saudi Arabia over the period 1985-1989. All 35 Saudi stocks show a significant departure from the random walk with an average lag-one autocorrelation coefficient of -0.471. This coefficient is opposite in sign and is huge in magnitude relative to autocorrelations reported in the studies of other stock markets. Omet and Khasawneh (2002) find that over the period 1992-2000, the market index of the Jordanian stock market is not consistent with the efficient market hypothesis. In contrast, Ojah and Karemera (1999) find evidence that equity price indices (1987-1997) in major Latin American emerging equity markets (Argentina, Brazil, Chile and Mexico) follow a random walk, and that they are, in general, weak-form efficient.

The third line of research focuses on the market efficiency of non-stock markets. Using six daily exchange rates over the period 1973-1975, Cornell and Dietrich (1978) indicate that the foreign exchange market is efficient because of low return autocorrelations. Belaire-Franch and Opong (2005) examine ten pairs of exchange rates, all relative to the euro, using the parametric variance ratio tests developed by Lo and MacKinlay (1988) and the non-parametric variance ratio tests based on ranks and signs developed by Wright (2000). They conclude that most Euro exchange rates are weak-form efficient. Rashid (2006) uses Lo and MacKinlay's variance ratio tests to investigate five pairs of weekly exchange rates, all relative to the Pakistani Rupee, and finds that most of these exchange rates follow random walks. In contrast, by applying the same parametric variance-ratio tests to five pairs of weekly exchange rate series over the period 1974-1989, Liu and He (1991) provide evidence rejecting the random walk hypothesis.

In sum, the findings of market efficiency research in most developed stock markets tend to support the weak-form efficiency because of a low degree of dependence between returns. In contrast, the findings of similar research in many non-developed stock markets are mixed. The problem of thin trading normally makes emerging markets not as efficient as developed markets. Also, although papers typically find the foreign exchange market to be weak-form efficient in most exchange rates, many studies do reject the random walk hypothesis in some exchange rates.

III. Data and Methodology

We compiled the daily exchange rates ($/British pound, $/euro, $/Swiss franc, and $/yen) in New York at noon from the Federal Reserve of the U.S. over the period January 1999-December 2011. Thus, for each time series we collect 3270 data points.

We first analyzed data for normality to determine whether serial correlations methods would be appropriate, using the following three tests: Kolmogorov-Smirnov (KS), Kolmogorov-Smirnov test with the Lilliefors Correction (KSLC), and Shapiro-Wilk (SW). The null hypothesis is that the exchange rate is normally distributed and the alternative hypothesis is that the exchange rate is not normally distributed. Table 1 presents the normality test results for each exchange rate and for each test. As we can see, for each exchange, the null hypothesis is rejected. These rejections indicate that each of the four exchange rates is not from a normal distribution and that autocorrelation methods are not appropriate for testing these exchange rate series.

Table 1 Normality test results for the four exchange rates

FX Rate	KS	KSLC	SW
$/£	7.62	0.13	0.94
$/€	4.69	0.08	0.96
$/SF	3.46	0.06	0.97
$/¥	9.60	0.17	0.88

SF = Swiss franc
KS = Kolmogorov-Smirnov; KSLC = Kolmogorov-Smirnov test with the Lilliefors Correction; and SW = Shapiro-Wilk
The KS (KSLC, or SW) column shows the test statistics for each of the four exchange rates
N = 3270 daily observations; time period = January 1999 to December 2011
Note: The p-values of all test statistics are equivalent to 0

When the time series data are not normally distributed, non-parametric tests for randomness are recommended. The null hypothesis is that the exchange rate is from a random sequence and the alternative hypothesis is that the exchange rate is not from a random sequence. We employ two popular non-parametric tests of randomness with brief explanations as follows.

A. Runs Up and Down Tests

For numerical observations, we also looked at the difference between two consecutive observations $X_{i+1} - X_i$. If an observation was equal to its preceding observation we ignored it and reduced the value of n by 1. When the number of observation is large, say, n > 25, the distribution of runs, R, is normally distributed with

$$\mu_r = \frac{2n-1}{3}$$

$$\sigma_r = \sqrt{\frac{16n-29}{90}}$$

The two sided significance level is based upon

$$z = \frac{R - \mu_r}{\sigma_r}$$

B. Runs Above and Below a Central Point Tests

For each data point in a sequence, the difference, $D_i = X_i -$ CentralPoint, is calculated. The first central point we used is the median of the data. The second central point we utilized is the mean of the data. If $D_i \geq 0$, the difference is considered positive and it is considered negative otherwise. n_+ is the number of positive signs, n_- is the number of negative signs, and R is the number of runs or sign changes plus 1. For n_+ or n_- greater than 20, the sampling distribution for the number of runs is approximately normal with

$$\mu_r = \frac{2n_+n_-}{n_+ + n_-} + 1$$

$$\sigma_r = \sqrt{\frac{2n_+n_-(2n_+n_- - n_+ - n_-)}{(n_+ + n_-)^2(n_+ + n_- - 1)}}$$

The two sided significance level is based upon

$$z = \frac{R - \mu_r}{\sigma_r}$$

IV. Empirical Findings and Interpretations

Table 2 shows the results of the runs up and down test for each of the four exchange rates. As we can see, the null hypothesis is rejected for each exchange rate. The actual number of runs is significantly less than expected. These rejections indicate that each exchange rate does not follow a random walk or is not weak-form efficient.

Table 2 Results of the runs up and down test for the random walk hypothesis (RWH)

FX Rate	Actual runs	Expected runs	Z statistic	p value
$/£	1666	2162.33	-20.67	0.00
$/€	1672	2160.33	-20.35	0.00
$/SF	1672	2166.33	-20.57	0.00
$/¥	1667	2165.00	-20.73	0.00

SF = Swiss franc
N = 3270 daily observations; time period = January 1999 to December 2011
Null hypothesis: the exchange rate follows a random walk
Alternative hypothesis: the exchange rate does not follow a random walk

Table 3 shows the results of the runs above and below median tests (in Panel A) and the results of the runs above and below mean tests (in Panel B) for each of the four exchange rates. As we can see, the actual number of runs is significantly less than expected and the null hypothesis is rejected for each exchange rate and for each of the two methods. These rejections indicate that each of the four exchange rates does not follow a random walk or is not weak-form efficient.

Table 3 Results of the runs above and below median (Panel A) and results of the runs above and below mean (Panel B) tests for the random walk hypothesis (RWH)

Panel A

FX Rate	Median	Total N	Actual runs	Z statistic	p value
$/£	1.62	3270	74	-54.64	0.00
$/€	1.24	3270	32	-56.11	0.00
$/SF	0.80	3270	62	-55.06	0.00
$/¥	0.01	3270	68	-54.85	0.00

Panel B

FX Rate	Mean	Total N	Actual runs	Z statistic	p value
$/£	1.68	3270	17	-56.61	0.00
$/€	1.21	3270	52	-55.36	0.00
$/SF	0.80	3270	74	-54.64	0.00
$/¥	0.01	3270	72	-54.45	0.00

SF = Swiss franc
N = 3270 daily observations; time period = January 1999 to December 2011
Null hypothesis: the exchange rate follows a random walk
Alternative hypothesis: the exchange rate does not follow a random walk

Our findings in Tables 2 and 3 are not consistent with those of Cornell and Dietrich (1978), who find that the foreign exchange market is weak-form efficient. However, Liu and He (1991) show that the exchange rates do not follow a random walk. There are three possible explanations. First, government interventions in the foreign exchange market often lead to distortions in the exchange rates. Second, the overshooting or undershooting phenomenon, suggested by Liu and He (1991), may make the currency market less efficient. Third, when two countries are in two different time zones, the exchange rate between two currencies of these countries may not reflect the information from these two countries immediately. For example, the yen-dollar exchange rate in New York may not incorporate the information from Japan in a timely fashion. If the foreign exchange market is not weak-form efficient, investors may be able to formulate a profitable trading strategy to explore the inefficiencies.

V. Summary and Conclusions

This paper studies the behavior of the four daily exchange rates ($/£, $/€, $/Swiss franc, and $/¥) over the period 1999-2011. These exchange rates include the most traded currencies worldwide.

Our major findings are as follows. First, each of the four exchange rates is not normally distributed. Second, each exchange rate does not follow a random walk in the runs up and down test. Third, each exchange rate does not follow a random walk in the runs above and below a central point test. We suggest that two currencies in different time zones, government interventions, and exchange rate overshooting or undershooting may play a role in market inefficiency. If the transaction cost is small and the foreign exchange market is not weak-form efficient, investors may be able to explore profitable opportunities.

Overall, this paper extends the existing literature in market efficiency by examining the exchange rates that are traded the most worldwide. Our new evidence suggests that these major exchange rates do not follow a random walk. This finding is not consistent with what the literature suggests.

References

Belaire-Franch, Jorge, and Kwaku Opong, 2005, Some evidence of random walk behavior of Euro exchange rates using ranks and signs, *Journal of Banking & Finance* 29, 1631-1643.

Butler, Kurt C. and S.J. Malaikah, 1992, Efficiency and inefficiency in thinly traded stock markets: Kuwait and Saudi Arabia, *Journal of Banking & Finance* 16, 197-210.

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Cornell, W. Bradford and J. Kimball Dietrich, 1978, The efficiency of the market for foreign exchange under floating exchange rates, *Review of Economics and Statistics* 60(1), 111-120.

Fama, Eugene, 1965, The behavior of stock market prices, *Journal of Business* 38(1), 34–105.

Fama, Eugene, 1970, Efficient capital markets: A review of theory and empirical work, *Journal of Finance* 25(2), 383–417.

Fama, Eugene, 1991, Efficient capital markets: II, *Journal of Finance* 46(5), 1575–1617.

Groenewold, Nicolaas, 1997, Share market efficiency: Tests using daily data for Australia and New Zealand, *Applied Financial Economics* 7(6), 645-657.

Hawawini, Gabriel and Pierre Michel, 1984, European Equity Markets: A Review of the Evidence on Price Behavior and Efficiency in European Equity Markets: Risk, Return and Efficiency, Garland Publishing Company, New York and London.

Liu, Christina Y. and Jia He, 1991, A variance-ratio test of random walks in foreign exchange rates, *Journal of Finance* 46(2), 773-785.

Lo, Andrew and A. MacKinlay, 1988, Stock market prices do not follow random walks: evidence from a simple specification test, *Review of Financial Studies* 1, 41-66.

Ojah, Kalu and David Karemera, 1999, Random walks and market efficiency tests of Latin American emerging equity markets: A revisit, The *Financial Review* 34, 57-72.

Omet, G., Khasawneh, M., & Khasawneh, J., 2002, Efficiency tests and volatility effects: Evidence from the Jordanian stock market, *Applied Economic Letters* 9, 817-821.

Poshakwale, S., 1996, Evidence on the weak-form efficiency and the day of the week effect in the Indian stock market, *Finance India* 10, 605-616.

Rashid, Abdul, 2006, Do exchange rates follow random walks? An application of variance-ratio test, *Pakistan Economic and Social Review* 44(1), 57-79.

Samuelson, Paul, 1965, Proof that properly anticipated prices fluctuate randomly, *Industrial Management Review* 6, 41-49.

Wright, Jonathan, 2000, Alternative variance-ratio tests using ranks and signs, *Journal of Business & Economic Statistics* 18(1), 1-9.