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Is the Foreign Exchange Market Efficient? Evidence from the Behavior of Major Exchange Rates

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This paper studies the behavior of the three daily exchange rates (U.S. dollar/Brazilian real, U.S. dollar/Canadian dollar, and U.S. dollar/Mexican peso) with 3,270 observations over the period 1999-2011, rejecting that each exchange rate series is random. 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 tests. Third, each exchange rate does not follow a random walk in the runs above and below a central point tests. We suggest that non-Eurocurrencies, exchange rate overshooting or undershooting, and government interventions 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 arbitrage opportunities. Overall, our new evidence suggests that some exchange rates do not follow a random walk, which is not consistent with the literature.

JEL Codes: F31 and G14

1. Introduction

Financial markets play an important role in allocating resources, providing funds, enhancing risk sharing, and hence promoting economic growth. Efficient financial markets can facilitate the transactions between buyers and sellers, generate continuous prices, and produce fair prices. Because of its importance, the topic of market efficiency has long interested academics, practitioners, and regulators.

Fama (1970) suggests that securities prices in efficient markets always fully reflect available information. This is the efficient market hypothesis (EMH). He further categorizes efficient markets into three forms in terms of the information set. First, if historical prices (i.e., the information set) are not related to future prices, then the market is weak-form efficient. Second, the market is semi-strong form efficient if securities prices fully incorporate all publicly available information (a larger information set). 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.

Because it is more complicated to test the semi-strong form and strong form market efficiency, most existing studies investigate whether or not the market is weak-form efficient, using stock price data. With some exceptions, the stock markets in developed countries tend to be weak-form efficient while the stock markets in a few emerging-market

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countries are not. If financial markets are not efficient, one implication is that there may exist arbitrage opportunities for investors.

This paper is different from most of previous studies on market efficiency in four important ways. 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 not used to raise 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. Finally, we focus on the exchange rate, in which the financial markets of two countries are open at the same time. Note that each exchange rate involves two currencies of two countries. This means that economic and political news from both countries can be incorporated into the exchange rate immediately.

After examining the three daily exchange rates (U.S. dollar/Brazilian real, U.S. dollar/Canadian dollar, and U.S. dollar/Mexican peso) with 3,270 observations over the period 1999-2011, we obtain the following results. First, each of the three exchange rates is not normally distributed. Second, each exchange rate does not follow a random walk in the runs up and down tests. Third, each exchange rate does not follow a random walk in the runs above and below a central point tests. We suggest that non-Eurocurrencies, exchange rate overshooting or undershooting, and government interventions may play a role in market inefficiency.

The remainder of this paper is organized as follows. Section 2 briefly discusses the related literature. In Section 3, we describe the data and methodology. Section 4 presents and discusses empirical results. We summarize and conclude in Section 5.

2. 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 stock market efficiency in developed countries. 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) find 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 past prices, supporting the weak-form efficiency of the EMH.

The second line of research looks into the efficiency of stock markets in non-developed countries. 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, Khasawneh 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) show evidence that equity price indices (from 1987 to 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. After investigating eight emerging markets in the Middle East and North Africa, Al-Khazali, Ding and Pyun (2007) conclude that they cannot reject the random walk hypothesis for these markets. More recently, Okpara (2010) find that the stock market in Nigeria is weak-form efficient.

The third line of research investigates the market efficiency of non-equity 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. In contrast, by applying a variance-ratio test developed in Lo and MacKinlay (1988) 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 stock markets of non-developed countries are mixed. One possible explanation is that thin trading may make emerging markets not as efficient as developed markets.

3. Data and Methodology

We compiled the daily exchange rates (U.S. dollar/Brazilian real, U.S. dollar/Canadian dollar, and U.S. dollar/Mexican peso) in New York at noon from the Federal Reserve of the U.S. over the time period extending from the beginning of January 1999 to the end of December 2011. Thus, for each time series (exchange rate) we collect 3270 data points.

Our sample size is much larger than those of many previous studies on market efficiency because we use daily data, instead of weekly or monthly data.

When the prices of a security move randomly, these prices should be normally distributed. The normal distribution of a security's prices is one basic assumption that underlies the random walk theory and, therefore, the efficient market hypothesis (EMH). Before deciding which methods would be appropriate for testing the randomness of exchange rates, we need to test the normality of these exchange rates. Following previous empirical work in the literature, we conducted three normality tests on the data to determine whether serial correlations methods would be appropriate. These tests include Kolmogorov-Smirnov (KS), Kolmogorov-Smirnov test with the Lilliefors Correction (KSLC), and Shapiro-Wilk (SW), which are non-parametric and are used to check how well a time series of data fits the normal distribution.

In each of three normality tests, 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 method. For each exchange, the null hypothesis is rejected. These rejections indicate that each of three 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 three exchange rates

FX Rate	KS	KSLC	SW
$/BR	5.367	0.094	0.963
$/C$	8.433	0.147	0.917
$/MP	4.251	0.074	0.963

BR = Brazilian Real; C$ = Canadian Dollar; MP = Mexican Peso
KS = Kolmogorov-Smirnov test statistic
KSLC = Kolmogorov-Smirnov with the Lilliefors Correction test statistic
SW = Shapiro-Wilk test statistic
N = 3270 observations; time period = January 1999 to December 2011
Null hypothesis: The exchange rate is normally distributed
Alternative hypothesis: The exchange rate is not normally distributed
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 samples $X_{i+1} - X_i$. If an observation was equal to its preceding observation we ignored it and reduced the value of n by 1. When the number of observations 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

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

4. The Findings

Table 2 shows the results of the runs up and down test for each of the three 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

FX Rate	Actual runs	Expected runs	Z statistic	p value
$/BR	1580	2136.333	-23.313	0.000
$/C$	1623	2157.000	-22.270	0.000
$/MP	1611	2165.667	-23.086	0.000

BR = Brazilian Real; C$ = Canadian Dollar; MP = Mexican Peso
N = 3270 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 presents the results of the runs above and below median and mean tests for each of the three exchange rates. It is shown that the actual number of runs is significantly less than expected and the null hypothesis is rejected for each exchange rate and for each of two methods. These rejections indicate that each of the three exchange rates does not follow a random walk or is not weak-form efficient.

Table 3: Results of the runs above and below median and mean tests for the random walk hypothesis

FX Rate	Median	Total N	Actual runs	Z statistic	p value
$/BR	0.477	3270	21	-56.493	0.000
FX Rate	Mean	Total N	Actual runs	Z statistic	p value
$/BR	0.475	3270	23	-56.423	0.000
FX Rate	Median	Total N	Actual runs	Z statistic	p value
$/C$	0.813	3270	46	-55.619	0.000
FX Rate	Mean	Total N	Actual runs	Z statistic	p value
$/C$	0.813	3270	46	-55.619	0.000
FX Rate	Median	Total N	Actual runs	Z statistic	p value
$/MP	0.092	3270	74	-54.639	0.000
FX Rate	Mean	Total N	Actual runs	Z statistic	p value
$/MP	0.093	3270	82	-54.344	0.000

BR = Brazilian Real; C$ = Canadian Dollar; MP = Mexican Peso
N = 3270 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 of 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) and Chiou and Willems (2012) show that the exchange rates do not follow a random walk. In the case of the three exchange rates in our sample, the financial markets of Brazil, Canada, Mexico, and the U.S. are open during similar hours in a business day. The determination of an exchange rate in any two of these four countries can, in theory, incorporate all news from the financial markets of these two countries. Even so, each of these three exchange rates is still not weak-form efficient. What can be the reasons?

We offer three possible explanations. First, the international Fisher effect suggests that the difference in the nominal interest rates of two countries reflects the expected change in the spot exchange rate between the currencies of these two countries. In actual pricing, the interest rates of Eurocurrencies are normally used. However, it seems that the currencies of Brazil, Canada, and Mexico are not part of actively used Eurocurrencies. Second, the overshooting or undershooting phenomenon, suggested by Liu and He (1991), may make the currency market less efficient. Dornbusch (1976) argues that when an exogenous variable changes, the short-run effect on the exchange rate can be greater than the long-run effect. Therefore, the exchange rate in the short-run overshoots its new equilibrium long-run value. Third, government interventions in the foreign exchange market often lead to distortions in the exchange rates. For example, on September 13, 2012, the Federal Reserve of the U.S. announced QE3 (Quantitative Easing 3), resulting in the depreciation of the U.S. dollar against many other currencies.

5. Summary and Conclusions

This paper studies the behavior of the three daily exchange rates (U.S. dollar/Brazilian real, U.S. dollar/Canadian dollar, and U.S. dollar/Mexican peso) over the period 1999-2011. Because the financial markets in these four countries are open during similar hours, each exchange rate can fully and immediately reflect economic and political news from both countries. In this aspect, our paper is different from previous studies on market efficiency of exchange rates, including Cornell and Dietrich (1978), Liu and He (1991), and Chiou and Willems (2012).

Our major findings are as follows. First, each of the three exchange rates is not normally distributed. Second, each exchange rate does not follow a random walk in the runs up and down tests. Third, each exchange rate does not follow a random walk in the runs above and below a central point tests. We suggest that non-Eurocurrencies, exchange rate overshooting or undershooting, and government interventions 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 arbitrage opportunities.

Overall, this paper extends the existing literature in market efficiency by examining the exchange rates that can immediately reflect new information from both countries involved in each exchange rate. Our new evidence suggests that some exchange rates do not follow a random walk, which is not consistent with the literature.

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