Martingale difference hypothesis and financial crisis: Empirical evidence from European emerging foreign exchange markets

Dorina Lazăr a,*, Alexandru Todea b, Diana Filip a

a Department of Statistics, Forecasting, Mathematics, Faculty of Economics and Business Administration, Babes-Bolyai University, Teodor Mihali 58-60, 400591 Cluj-Napoca, Romania
b Department of Finance, Faculty of Economics and Business Administration, Babes-Bolyai University, Teodor Mihali 58-60, 400591 Cluj-Napoca, Romania

1. Introduction and motivation

In an efficient foreign exchange market, the exchange rates reflect, by the actions of rational investors, all information relevant to their fundamental value. Focusing on the weak form of informational efficiency, the martingale stochastic model provides an appropriate framework for testing whether exchange returns are predictable. The weak form efficiency implies that the past...
exchange rates cannot help to improve forecasts about future spot exchange rates; therefore there are no opportunities for profit based upon past data.

The efficient market hypothesis asserts that markets are efficient concerning information. Depending on the information set in setting prices, Fama (1970) classifies market efficiency into three categories; namely, weak-form, semi-strong and strong-form efficiency. A market is weak-form efficient if current prices fully and quickly incorporate the information contained in historical prices. In addition to the history of past prices, the semi-strong and strong forms of efficiency consider the publicly respectively privately available information. This paper focuses on the weak-form efficiency of foreign exchange markets. This is related to the ability to predict foreign exchange rate changes based on historical exchange rates.

As Escanciano and Lobato (2009) point out, the lack of predictability of financial series has been commonly referred to as the random walk hypothesis, with some confusing meanings. Within the terminology of Campbell et al. (1997), the dynamic of prices can be described by three different processes: a random walk with independently and identically distributed increments (random walk 1), a random walk with independent but not identically distributed increments (random walk 2), and by the weakest form of random walk hypothesis, which includes processes with uncorrelated changes (random walk 3).

The present paper investigates if the successive exchange rate returns follow a martingale difference sequence; this would imply that the log of exchange rate follows a martingale process. As Escanciano and Lobato (2009) observed, a martingale process for prices corresponds to the random walk 2 hypothesis within the previous terminology. Under this hypothesis the increments, given by the exchange rate returns, are mean-independent. The past and current data are of no use for forecasting future values of exchange rate returns; no linear or nonlinear dependence can be detected in the conditional mean.

The dynamics of exchange rates, in terms of efficiency/inefficiency behavior, is of interest for investors and traders, policy makers, monetary and fiscal authorities, and economic agents. The exchange rate movements affect the international trade flows, balance of payments and allocation of resources in national and international economy. On the other hand, foreign direct investment has a positive impact on the host country’s economic growth (Masca and Vaidean, 2009). The regulators, through policy instruments, aim at improving the informational inefficiency of the markets, at reducing the associated risks, and at ensuring economic stabilization. Evaluation of the degree of financial efficiency for Central and Eastern European (CEE) countries is important to assess to what extent these countries are prepared for the transition towards full monetary integration. Financial markets could provide stabilization in economies affected by specific shocks as long as they are efficient and integrated, substituting the traditional policy instruments (Vieira and Vieira, 2007).

A number of studies investigate the efficiency of financial markets, most of them using various versions of the variance ratio test. Charles and Darne (2009a,b) provide a good survey of the recent developments related to the variance-ratio tests. Also, Hoque et al. (2007) make a brief comparative description of these tests. The papers of Liu and He (1991), Ajayi and Karemera (1996), Wright (2000), Azad (2009) and Lin et al. (2010), among others, have studied the foreign exchange market efficiency. Belaire-Franch and Opong (2005) examine the behavior of ten major trading currencies quoted against the euro. With small exceptions, the empirical results reveal that the markets are weak-form efficient. Belaire-Franch and Opong (2010) test for random walk behavior of euro exchange rates using the variance ratio tests based on the subsampling approach; the results are mixed.

Escanciano and Velasco (2006) developed and applied a generalized spectral (GS) test for the martingale difference hypothesis (MDH) for five exchange rates and the results suggest the presence of some nonlinear dependencies in the conditional mean. Charles et al. (2010) applied the GS test to look for predictability of the five major foreign exchange markets. The simulation experiments conducted by Charles et al. (2011) show that the wild bootstrap automatic variance ratio test of Kim (2009) has highest power against linear dependence, while the GS test has high power against nonlinear dependence; the authors suggest to use both tests in practice.

Other groups of studies use the Hurst exponent to assess informational efficiency (Da Silva et al., 2007; Qian and Rasheed, 2010). Giannellis and Papadopoulos (2009) investigate the efficiency of CEE foreign exchange markets using a test procedure based on equilibrium exchange rates. As a general
rule, the conclusions about the predictability of exchange rate returns depend on the exchange market, the applied methodology and the covered period.

As far as we know, there are few studies investigating the impact of financial crises on the degree of efficiency of foreign exchange markets. Most of the empirical and theoretical studies focus on the impact of the 1997 Asian financial crisis on the financial markets. Jeon and Seo (2003) investigate whether the Asian financial crisis affected the foreign exchange market efficiency in four Asian countries hardly hit by the crisis. The empirical evidence revealed weaker market efficiency immediately after the crisis than before the crisis, but market efficiency was recovered quickly, as shown by the regained cointegrating relationships for the pairs of the spot-forward exchange rates. Oh et al. (2007) found that the efficiency of markets with small liquidity such as Asian foreign exchange markets improved significantly after the Asian currency crisis; the authors used approximate entropy, a quantitative measure developed in statistical physics to quantify the randomness in the time series. Aroskar et al. (2004) studied the effects of the 1992 Western European currency crisis on developed markets' efficiency. The authors found cointegrating relationships among European currencies during the pre-crisis, crisis and post-crisis periods and analyzed the implications of these results for inefficiency.

This study investigates the martingale difference hypothesis (MDH) for six foreign exchange emerging markets in Central and Eastern Europe, using one of the most recent and powerful tests for returns predictability. Escanciano and Velasco's (2006) generalized spectral (GS) test is a spectral-based test, testing the null of MDH, which is able to detect a wide range of linear and non-linear dependence in the conditional mean, allowing for a general form of unknown conditional heteroskedasticity.

The main objective of the present study is to measure the effects of the recent global financial and economic crisis on the relative efficiency of the CEE foreign exchange markets. The rolling sample approach aims at monitoring the evolution of market efficiency over time and allows us to assess the relative efficiency of markets pre-crisis and during the crisis periods, respectively. Therefore, comparatively assessing the degree of financial markets efficiency, the CEE foreign exchange emerging markets are ranked using as indicator the percentage of time windows in which the hypothesis of martingale is not rejected. The absolute and relative efficiency over the entire period, namely from January 2004 to February 2011, is also investigated.

The paper is organized as follows. Section 2 describes the sample data and descriptive statistics. Section 3 is devoted to a short presentation of the methodology. Empirical results are analyzed in Section 4. Section 5 briefly concludes.

2. Data and descriptive analysis of CEE foreign exchange markets

The data consist of daily euro foreign exchange rates for six Central and Eastern European currencies, namely the Czech koruna, the Hungarian forint, the Polish zloty, the Romanian leu, the Russian ruble and the Turkish lira. The time series cover the period from January 2004 to February 2011.\footnote{The data source is the European Central Bank Database.} The currency time series present one or more structural changes for various reasons, such as institutional changes, structural reforms, an abrupt change in the underlying fundamentals, or major changes in the exchange rate regime (Kocenda, 2005); one of them is related with the recent financial crisis.

These countries experienced various kinds of exchange rate regimes, being more or less managed, usually through exchange rate interventions of the monetary authorities. In a floating exchange rate arrangement the movements of the currency are freely determined according to the foreign exchange market forces. However, for emerging markets, occasional market interventions of monetary authorities are not excluded, usually in an attempt to prevent a very high volatility of the national currency or to avoid excessive appreciation or depreciation unjustified by fundamentals of exchange rates.

The exchange rate regimes can be difficult to categorize because of differences between the de jure arrangements declared by the national authorities and their de facto exchange rate practices, and
because of the different methods and assumptions used to categorize de facto regimes.² Table A1 gives a short description of the exchange rate arrangements of selected CEE countries during the 2004–2011 period using the IMF staff classification system (adopted since 1999, and revised in 2009³) and the de facto exchange rate regime classifications proposed by Reinhart and Rogoff (2004).⁴ Both classifications indicate the floating regime, including managed float and free float, as dominant in Poland, Romania and Turkey. In other countries, namely Hungary and Russia, there were also limited periods with an intermediate regime (basket peg, crawling peg or band peg). Despite different names or definitions for exchange rate arrangements, the Czech Republic and Poland have had the most flexible exchange rate regimes in the CEE region.

The global economic and financial crisis had a deep impact on the CEE emerging market economies mainly since late 2008 (Gardo and Reiner, 2010). The exchange rates markets were strongly affected along with the international capital flows in the region. The early stage of the crisis was accompanied by a sharp depreciation of the national currencies. In the following, the beginning of the financial crisis is settled as the day when the sharp depreciation of the exchange rate started in the second half of 2008. Table 1 indicates the pre-crisis and crisis periods; in Fig. 1 these two sub-periods are separated by a vertical gray line.

A visual inspection of the movement of nominal exchange rates during the crisis distinguishes two stages. An early stage of the crisis accompanied by an abrupt upwards trend started in late 2008 and continued until March 2009 for the Turkish lira and the Hungarian forint and until February 2009 for the other currencies; the end of the first stage of the crisis is marked in Fig. 1 by a vertical gray dotted line.

In the early stage of the crisis the Polish zloty, Hungarian forint and Russian ruble were the currencies with the highest depreciation, while the Romanian leu recorded the lowest depreciation against the euro. The Polish zloty depreciated by 52% from the end of July 2008 to mid-February 2009. The Romanian leu recorded a lower depreciation of about 25% from September 2008 to February 2009. It is valuable to remember that Poland and Hungary use a free floating exchange rate regime, while Romania practices a floating regime accompanied by some direct foreign exchange market interventions of the central banks (including during the recent crisis). In the second stage of the crisis, the currencies experienced successive periods of appreciation/depreciation over a general trend of appreciation, excepting the Romanian leu. The appreciation trend was more pronounced for the Czech koruna and the Polish zloty.

² Hagen and Zhou (2005) provide an empirical study on the discrepancies between official exchange rate regimes and de facto exchange rate policies in transition economies.
³ The 2009 IMF revised system for classification of exchange rate arrangements replaces managed and independent floating with two new categories: floating and free floating.
⁴ There are some other de facto exchange rate regime classifications proposed in the literature; Tavlas et al. (2008) describe the main methodologies for classifying exchange rate arrangements.

Table 1
Descriptive statistics of exchange returns, for pre-crisis and crisis periods.

<table>
<thead>
<tr>
<th>Currency</th>
<th>Period</th>
<th>Mean (%)</th>
<th>St. dev. (%)</th>
<th>Skewness</th>
<th>Excess kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-crisis period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Czech koruna</td>
<td>1/2/2004–7/21/2008</td>
<td>−0.0295</td>
<td>0.3062</td>
<td>−0.241</td>
<td>1.606</td>
</tr>
<tr>
<td>Hungarian forint</td>
<td>1/2/2004–7/25/2008</td>
<td>−0.0105</td>
<td>0.4689</td>
<td>0.195</td>
<td>1.316</td>
</tr>
<tr>
<td>Polish zloty</td>
<td>1/2/2004–7/28/2008</td>
<td>−0.0327</td>
<td>0.4600</td>
<td>0.260</td>
<td>1.378</td>
</tr>
<tr>
<td>Romanian leu</td>
<td>1/2/2004–8/6/2008</td>
<td>−0.0142</td>
<td>0.5386</td>
<td>1.377</td>
<td>14.718</td>
</tr>
<tr>
<td>Russian ruble</td>
<td>1/2/2004–10/27/2008</td>
<td>−0.00619</td>
<td>0.3908</td>
<td>−0.171</td>
<td>2.699</td>
</tr>
<tr>
<td>Turkish lira</td>
<td>1/2/2004–5/2/2008</td>
<td>−0.00169</td>
<td>0.8894</td>
<td>0.980</td>
<td>4.397</td>
</tr>
<tr>
<td>Crisis period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Czech koruna</td>
<td>7/22/2008–2/28/2011</td>
<td>0.00874</td>
<td>0.5759</td>
<td>0.219</td>
<td>4.557</td>
</tr>
<tr>
<td>Hungarian forint</td>
<td>7/28/2008–2/28/2011</td>
<td>0.0227</td>
<td>0.9063</td>
<td>0.521</td>
<td>4.017</td>
</tr>
<tr>
<td>Polish zloty</td>
<td>7/29/2008–2/28/2011</td>
<td>0.0316</td>
<td>0.9188</td>
<td>0.207</td>
<td>2.649</td>
</tr>
<tr>
<td>Romanian leu</td>
<td>8/7/2008–2/28/2011</td>
<td>0.0289</td>
<td>0.4613</td>
<td>0.286</td>
<td>7.615</td>
</tr>
<tr>
<td>Russian ruble</td>
<td>10/28/2008–2/28/2011</td>
<td>0.0262</td>
<td>0.6788</td>
<td>0.869</td>
<td>4.923</td>
</tr>
<tr>
<td>Turkish lira</td>
<td>9/3/2008–2/28/2011</td>
<td>0.0389</td>
<td>0.9025</td>
<td>−0.168</td>
<td>9.769</td>
</tr>
</tbody>
</table>
Fig. 1. Foreign exchange rates time series, from January 2004 to February 2011.
The descriptive statistics for exchange returns, computed as $Y_t = 100 \cdot \ln(P_t/P_{t-1})$, where $P_t$ and $P_{t-1}$ denote the exchange rate on two consecutive trading days, for the pre-crisis and crisis periods are provided in Table 1. In the pre-crisis period, the sample mean returns are negative for all currencies, indicating an appreciation trend of the national currencies against the euro. The appreciation was higher for the Czech koruna and the Polish zloty, the daily mean returns being about 0.03%. The standard deviation, as a measure of the exchange returns volatility, ranges between 0.31% (for the Czech koruna) and 0.89% (for the Turkish lira).

The escalation of the global financial crisis in 2008 adversely affected the evolution of the national currencies. The pre-crisis trend of appreciation changed to a sharp depreciation mainly in the early stage of the crisis, covering the second half of 2008 and the first months of 2009. The daily mean returns were positive for all currencies. The financial crisis also had a significant impact on volatility and implicitly on the investor-assumed risk, the standard deviation of returns recording an increase from the pre-crisis to the crisis period for all countries except Romania. The Romanian leu recorded another episode of high volatility in the pre-crisis period, from the end of 2004 to mid-2005, which can be related to the capital account liberalization from April 2005 and to the national currency denomination. The early stage of the financial crisis was accompanied by a dramatic increase in volatility as a result of the impact of global crisis on the national economies.

The daily returns are mostly positively skewed and the level of excess kurtosis is positive. The Jarque–Bera test rejects the null hypothesis of returns’ normality distribution in pre-crisis and crisis periods for all currencies.

3. Methodology

Let $Y_t = \ln(P_t/P_{t-1})$ denotes the continuously compounded exchange rate return at time $t$, where $t=1, \ldots, n$. We are interested in testing if the stochastic discrete time process $(Y_t)_{t=1}^n$ follows a martingale difference sequence.

Escanciano and Velasco (2006) propose a generalized spectral (GS) test for the martingale difference hypothesis (MDH), which is able to detect linear and nonlinear dependence in the conditional mean. This is one of the most recent and powerful tests for returns predictability. The GS test considers dependence at all lags, is robust to conditional heteroskedasticity and consistent against a large class of uncorrelated non-martingale sequences. The Monte-Carlo experiments indicate that for almost all nonlinear alternatives the GS test has more empirical power than the other competing tests, also having good properties for linear models (Escanciano and Velasco, 2006; Charles et al., 2011).

The null hypothesis of interest is as follows: $H_0: E(Y_t|Y_{t-1}, Y_{t-2}, \ldots) = \mu$ almost surely, where $\mu$ is a real number. Escanciano and Velasco (2006) test the MDH hypothesis using a pairwise approach; the dependences at all lags available in the sample are taken into account. The null hypothesis can be formulated as:

$$H_0: \ m_j(y) = 0 \quad \text{a.s. for } \forall j \geq 1$$

where $m_j(y) = E[Y_t - \mu|Y_{t-j} = y]$ are the pairwise regression functions. The function $y_f(x) = E[(Y_t - \mu)e^{jY_{t-j}}]$ is used as a measure for conditional mean dependence in a nonlinear time series framework.

The above null hypothesis is consistent with the following: $H_0: \ y_f(x) = 0 \ \forall j \geq 1$ almost everywhere.

Under the null of MDH the generalized spectral distribution function $H(\lambda, x) = y_0(x) + 2 \sum_{j=1}^{\infty} y_j(x)(\sin j\pi \lambda / j\pi)$, where $\lambda \in [0, 1]$, becomes $H(\lambda, x) = y_0(x)\lambda$. The generalized spectral (GS) test considers the differences between sample estimates $\hat{H}(\lambda, x)$ and $H(\lambda, x) = \hat{y}_0(x)\lambda$, as follows:

$$S_T(\lambda, x) = (0.5T)^{1/2}\{\hat{H}(\lambda, x) - \hat{H}_0(\lambda, x)\}$$

Using the Cramer–von Mises norm to measure the distance of $S_T(\lambda, x)$ to zero for all possible values of $\lambda$ and $x$ and the cumulative distribution function of standard normal distribution as a weighting function, Escanciano and Velasco (2006) obtain the following test statistic:

$$D_n^2 = \frac{1}{n-1} \sum_{j=1}^{n-1} \frac{n-j}{(n-1)^2} \sum_{t=j+1}^{n} \sum_{s=j+1}^{n} (Y_t - \bar{Y}_{t-j})(Y_s - \bar{Y}_{s-j}) \exp[-0.5(Y_{t-j} - Y_{s-j})^2]$$

The null of MDH is rejected for large values of $D_n^2$. 

As the asymptotic null distribution of the test depends on the data generating process, Escanciano and Velasco (2006) propose to implement the test using a wild bootstrap procedure. The authors prove the validity of the bootstrap procedure, allowing approximating the p-value.

In our study, the GS test is conducted in a rolling time-window framework. The p-value of the test is computed for a window of 300 observations and then the sample is rolled one observation forward for re-estimation of the p-value. The percentage of time windows for which p is less than 5% is used as an indicator of relative efficiency as proposed by Lim (2007). The concept of relative efficiency may be more useful than absolute efficiency, as Campbell et al. (1997) point out.

The rejection of the hypothesis of efficiency over the whole sample period could hide sub-periods of efficiency or the fact that market efficiency evolves over time. Yilmaz (2003) tested for martingale property in a moving-window framework and found that during the times of coordinated central bank interventions seven major currencies deviated from martingale property. A number of studies examined the relative efficiency of stock markets in a rolling window approach using the bicorrelation test statistic (Todea and Zoicaş-lenciu, 2008; Lim, 2007; Lim et al., 2008; Lim and Brooks, 2010a,b). Cajuéiro and Tabak (2006) estimate Hurst exponents for each window to test for long-term linear dependence and use the median as a statistical measure when ranking the stock markets. Charles and Darne (2009a,b) examine the random walk hypothesis of major euro exchange rates, finding that they are weak-form efficient. Belaire-Franch and Opong (2010), using a subsampling approach, found that the random walk behavior is dominant among the three major currencies, namely the Japanese yen, the US dollar and the British pound.

4. Empirical results

4.1. Assessing the efficiency of exchange markets over the entire period

The null hypothesis of the martingale difference hypothesis of returns implies the absence of any dependence in foreign exchange returns, which could be modeled to generate improved point predictions. Testing the absolute market efficiency over the whole period, namely from January 2004 to February 2011, the GS test rejects the martingale difference hypothesis for the Russian ruble, the Romanian leu and the Turkish lira at a 5% level of significance.

The implementation of the GS test in a rolling window approach allows us to obtain inferential outcomes which are robust to possible structural changes and to rank the markets relative to their degree of efficiency. The graph of the p-values suggests an episodic behavior, providing empirical support for the adaptive market hypothesis of Lo (2004) rather than for a continuous improvement of the informational efficiency degree in time. Under the adaptive market hypothesis, the EMH and the behavioral finance co-exist; market efficiency is a characteristic that varies over time and across markets (Lim and Brooks, 2010a,b).

Similar results were obtained for developed foreign exchange markets by Charles et al. (2010). There can be observed an alternation of martingale sub-periods with non-martingale sub-periods, respectively of efficiency and inefficiency. Ranking the currencies in ascending order by the percentage of time windows for which p is less than 0.05, the first position is recorded by the Hungarian forint (the most efficient market), the highest predictability being detected for the Russian ruble and the Romanian leu.

The percentage of time windows for which market efficiency is rejected, the exchange returns being predictable, is higher than 50% for all currencies, as the z-test statistics indicate (Table 2). The percentage of sub-periods (windows) where the market was inefficient is higher than 50%.

4.2. Impact of the recent financial crisis on the exchange market efficiency

The computed p-values for each rolling time window for the pre-crisis and crisis periods are presented graphically in Fig. 2; the p-values corresponding to the crisis period are in the gray zone of

---

5 We would like to thank the authors Escanciano and Velasco (2006) for their generosity in sharing the Matlab code of the GS test. This code was improved for a rolling window approach.
the figure. The martingale hypothesis is rejected, in a time window, if the p-value is below the horizontal gray line (parallel to the X-axis), corresponding to a 5% significant level.

During the pre-crisis period, Fig. 2 shows that the non-martingale periods seem to be rather country-specific. A time-varying window approach makes it possible to identify the periods of market efficiency/inefficiency and to gain further insight into the causes that can explain the predictability of foreign exchange rates. The empirical results developed here may be a good starting point for further research focusing on the identification of shocks that alter the efficiency and the association of the periods of predictability to country-specific regional or international financial, economic and political events, to exchange rate regimes, to exchange rate/monetary policy or to financial crises.

For example, such a limited period of inefficiency can be observed for the Hungarian forint during 2006–2007. This period was accompanied by an austerity program, introduced by the Hungarian government in October 2006 in order to reduce the budget deficit. The non-martingale period for the Romanian leu around the year 2005 is associated with a sharp appreciation of the leu and high volatility returns. During this year the liberalization of the capital account, the national currency denomination, and the adoption of an inflation targeting monetary strategy took place. In Poland, inflation had a turning point around mid-2006, when the inflation rate started to increase. Measures taken by the central bank under the monetary policy of inflation targeting may be likely to induce changes on the foreign exchange market; a deeper analysis of the economy of Poland should be performed in order to find possible explanations for the non-martingale period around the end of 2006–2007.

Prior to the crisis, the percentages of sub-periods (time-windows) in which the markets were inefficient are higher than 50% for all currencies except the Turkish and Hungarian markets, where the percentage does not differ significantly from 50%, as the z-test statistics indicate.

Since the second half of 2008, when the global economic and financial crises hit the CEE economies severely, empirical analysis suggests a decrease of the degree of efficiency of foreign exchange markets compared with the pre-crisis period. The crisis adversely affected the efficiency of selected emerging CEE foreign exchange markets, especially those of Turkey and Russia. During a time of economic recession, it is expected that financial panic, liquidity crises, or the chaotic economic/financial environment lead to the formation of nonlinear dynamics, and thus cause a decrease of the degree of efficiency. The proportion of time windows for which the martingale difference hypothesis was rejected during the crisis is significantly higher than for the pre-crisis period, as Table 3 shows. During the crisis period, in relative efficiency terms, the Hungarian foreign exchange market was the most efficient, followed by the Polish market; higher predictability was detected for the Russian and Turkish foreign exchange markets.

A visual inspection of Fig. 2 clearly indicates that all selected foreign exchange markets experienced periods of inefficiency during the first stage of the global financial crisis; the end of the first stage of the crisis is marked by a vertical dotted line. As most p-values are close to zero, there was a significant departure from efficiency for all currencies. This first stage of the crisis, covering the second half of 2008 and the first months of 2009, was accompanied by an abrupt upwards trend of the foreign exchange rates.

In the second stage of the crisis the currencies experienced successive periods of efficiency/inefficiency. As Fig. 2 and Table 3 indicate, the Hungarian, Polish and Romanian exchange markets recovered market efficiency quickly. These results seem to be in line with Jeon and Seo (2003), who

Table 2
GS test over the entire period, January 2004–February 2011.

<table>
<thead>
<tr>
<th>Currency</th>
<th>GS test of Escanciano and Velasco; p-value</th>
<th>% of windows p \leq 0.05</th>
<th>z-Test statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech koruna</td>
<td>0.07</td>
<td>62.11</td>
<td>9.83*</td>
</tr>
<tr>
<td>Hungarian forint</td>
<td>0.07</td>
<td>54.10</td>
<td>3.27*</td>
</tr>
<tr>
<td>Polish złoty</td>
<td>0.06</td>
<td>63.60</td>
<td>11.13*</td>
</tr>
<tr>
<td>Romanian leu</td>
<td>0.00</td>
<td>65.75</td>
<td>13.00*</td>
</tr>
<tr>
<td>Russian ruble</td>
<td>0.00</td>
<td>69.60</td>
<td>16.75*</td>
</tr>
<tr>
<td>Turkish lira</td>
<td>0.03</td>
<td>58.27</td>
<td>6.62*</td>
</tr>
</tbody>
</table>

* Significance at the 5% level.
Fig. 2. Time series plots of the p-values from rolling GS test, in pre-crisis and crisis periods.
investigated the impact of the 1997 Asian financial crisis on the efficiency of foreign exchange markets. In the cases of Russia, Turkey and the Czech Republic, the sub-periods where the martingale hypothesis is rejected occur with a higher frequency; these markets continue to register a low degree of efficiency.

The periods of market inefficiency are usually related with the following: the central banks’ intervention, the exchange rate regime, the divergence between the equilibrium and official rate due to a parallel black market or to other causes (Charles et al., 2010). Regarding the central banks’ interventions, there are contradictory opinions according to which the interventions are associated with periods of increasing predictability (Lima and Tabak, 2008; Yilmaz, 2003), respectively the central bank intervention does not generate technical trading profits (Frenkel and Stadtmann, 2004). However, the central banks’ interventions aim to restore the equilibrium of the exchange rate and, as a consequence, to improve market functioning. A set of recent studies show that central bank interventions in the foreign exchange markets can move the exchange rate level in the desired direction and affect the volatility and exchange rate returns in the short run (Dominguez, 2006; Beine et al., 2009; Menkhoff, 2010). On the other hand, Asici (2011) found a strong causal relationship between the exchange rate regime and currency crises. Feridun (2009) investigates the determinants of exchange market pressure in Turkey.

The first stage of the crisis, when the selected foreign exchange markets experienced periods of inefficiency, was accompanied by some direct or indirect central bank interventions. During this period, most national currencies were more actively managed than in the years before the crisis. In the following, we provide a short description of some foreign exchange interventions, as mentioned in the literature.

The Czech National Bank has not engaged in direct interventions in the foreign exchange market since 2002 according to the IMF (IMF, Country Report No. 11/83). Poland also has one of the most free exchange regimes from the CEE region. As Baribula et al. (2011) emphasize, the central bank intervention of 9 April 2010 was the first and only intervention since 1998. In Hungary, the foreign exchange intervention was considered a temporary measure. The central bank rarely intervened and there were no large amounts involved; two verbal interventions of the central bank in the foreign exchange market occurred, one in 2009 and one in 2010 (Gereben et al., 2011). A verbal intervention took place in the first months of 2009 as a coordinated action of the central banks of the Czech Republic, Poland, Hungary and Romania, when the national currencies reached a record low level (Croitoru, 2011).

During the first stage of the crisis, the Central Bank of Russia engaged in substantial interventions in the foreign exchange market to avoid a depreciation of the ruble (Gurvich et al., 2010). In November 2008 a controlled depreciation strategy was initiated (Barisitz, 2009). The Central Bank of the Republic of Turkey (CBT) has taken the following announced measures, among others: the foreign exchange buying auctions were suspended starting from 16 October 2008, a total amount of USD 100 million.

---

**Table 3**
Rolling time window GS test results, for pre-crisis and crisis periods.

<table>
<thead>
<tr>
<th>Currency</th>
<th>% of windows for which ( p \leq 0.05 )</th>
<th>Equality ( t )-test for % Pre-crisis/crisis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-crisis period</td>
<td>Crisis period</td>
</tr>
<tr>
<td>Czech koruna</td>
<td>58.24</td>
<td>89.04</td>
</tr>
<tr>
<td>Hungarian forint</td>
<td>55.31</td>
<td>65.13</td>
</tr>
<tr>
<td>Polish zloty</td>
<td>60.43</td>
<td>71.73</td>
</tr>
<tr>
<td>Romanian leu</td>
<td>58.82</td>
<td>72.34</td>
</tr>
<tr>
<td>Russian ruble</td>
<td>64.46</td>
<td>96.01</td>
</tr>
<tr>
<td>Turkish lira</td>
<td>49.11</td>
<td>89.08</td>
</tr>
</tbody>
</table>

Significance at the 5% level.
was sold to the market through foreign exchange selling auctions on 24 October 2008 and 27 October 2008, and in December 2008 the banking system was supported with additional foreign currency liquidity from the foreign exchange reserves (CBT, 2010). Some direct interventions of the Romanian Central Bank were not announced as far as we know. However, as Croitoru (2011) points out, the bank sold a large amount of currency during the crisis; the foreign currency sales between October 2008 and 2010 represent 77.1% of total sales from the period 1999 to 2010. The sharp depreciation of the local currency in October 2008 has been attributed to a speculative attack (Croitoru, 2011).

5. Conclusions

This study investigates the efficiency of six CEE foreign exchange markets, focusing on the effects of the recent global economic and financial crisis on the relative efficiency. The generalized spectral test of Escanciano and Velasco (2006) was applied in a rolling window approach. This test was chosen due to its high performances in case of linear and especially nonlinear dependencies and its good asymptotic properties.

Over the full sample period, the statistical findings show that the Hungarian forint is the most unpredictable currency, followed by the Turkish lira, Czech koruna, Polish zloty and Romanian leu, while the Russian ruble is at the tail end of the ranking list according to the degree of the efficiency. Graphically, we observed an episodic behavior of linear or nonlinear dependencies, providing empirical support for the adaptive market hypothesis of Lo (2004) rather than for a continuous improvement of the informational efficiency degree in time. Therefore, the profit opportunities in the CEE foreign markets appear in an episodic way and do not disappear definitively.

To gain further information on the impact of the global crisis on exchange markets, the rolling GS statistics are computed for the pre-crisis and crisis periods. The empirical results show that the global crisis adversely affected the efficiency of most CEE foreign markets, with the Turkish lira being the hardest hit, followed by the Russian ruble, Czech koruna, Romanian leu, Polish zloty and Hungarian forint. This is not surprising, because during the financial crisis periods it is expected that financial panic, liquidity crisis or the chaotic economic/financial environment can lead to the formation of nonlinear dynamics, and thus cause a decrease of the degree of efficiency.

All foreign exchange markets experienced periods of inefficiency during the first stage of the crisis, covering the second half of 2008 and the first months of 2009; during this period the currencies recorded a sharp depreciation. In the second stage of the crisis, the Hungarian, Polish and Romanian foreign markets recovered market efficiency quickly, while Russia, Turkey and the Czech Republic continue to register a low degree of efficiency.

Acknowledgements

The authors would like to express their gratitude to the editor and anonymous reviewers for their constructive comments and suggestions on an earlier version of this paper. This work was supported by CNCSIS-UEFISCSU, Project number PNII-ID-2366/2008.

Appendix

Table A1

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Czech Republic</td>
<td>2004–2007: managed floating with no predetermined path</td>
<td>De facto crawling band around euro (±5%)</td>
</tr>
<tr>
<td></td>
<td>2008–2009: independent floating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2009–: free floating</td>
<td></td>
</tr>
</tbody>
</table>
Table A1 (Continued)

<table>
<thead>
<tr>
<th>Country</th>
<th>Exchange rate arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMF classification</td>
<td>Reinhart and Rogoff (2004) classification</td>
</tr>
<tr>
<td>Primary/secondary</td>
<td></td>
</tr>
<tr>
<td>Hungary</td>
<td>2004–February 2008: peg against euro, with band (±15%)</td>
</tr>
<tr>
<td></td>
<td>February 2008–November 2008: free floating</td>
</tr>
<tr>
<td></td>
<td>November 2008–: floating</td>
</tr>
<tr>
<td>Poland</td>
<td>2004–2009: independent floating</td>
</tr>
<tr>
<td></td>
<td>2009–: free floating</td>
</tr>
<tr>
<td>Romania</td>
<td>2004–2009: managed floating with no predetermined path</td>
</tr>
<tr>
<td></td>
<td>2009–: floating</td>
</tr>
<tr>
<td>Russia</td>
<td>2004–November 2008: managed float with no pre-determined path</td>
</tr>
<tr>
<td></td>
<td>November 2008–: other managed arrangement (controlled floating)</td>
</tr>
<tr>
<td>Turkey</td>
<td>2004–2009: independent floating</td>
</tr>
<tr>
<td></td>
<td>2009–: free floating</td>
</tr>
</tbody>
</table>

References


