Central Bank Review ISSN 1303-0701 print / 1305-8800 online

http://www.tcmb.gov.tr/research/review/

Are the Transition Stock Markets Efficient? Evidence from Non-Linear Unit Root Tests

Mübariz Hasanov

Department of Economics
Hacettepe University
Ankara, Turkey

muhas@hacettepe.edu.tr

Tolga Omay

Department of Economics
Cankaya University
Ankara, Turkey

omayt@cankaya.edu.tr

Abstract

In this paper we address efficiency of eight transition stock markets, namely, Bulgarian, Chinese, Czech, Hungarian, Polish, Romanian, Russian and Slovakian stock markets by testing whether the price series of these markets contain unit root. For this purpose we employ the nonlinear unit root test procedure recently developed by Kapetanios *et al.* (2003) that has a better power than standard unit root tests when series under consideration are characterised by a slower speed of mean reversion. The results of nonlinear unit root tests indicate that only Bulgarian, Czech, Hungarian and Slovakian price series contain unit root, consistent with weak form efficiency.

JEL Classification: C22, G14.
Keywords: Market Efficiency, Non-linear models, transition markets.

---

1. Introduction

The efficient market hypothesis states that security prices fully reflect all available information and that the price fluctuations are unpredictable. Unpredictability of returns is satisfied if stock prices follow a random walk, that is, stock prices are characterised by a unit root. Market efficiency has attracted a substantial interest of academicians (e.g., Fama, 1970, 1991; Lo and MacKinlay, 1988; Grieb and Reyes, 1999; Chaudhuri and Wu, 2003). Although there is vast literature on efficiency of both mature and emerging markets, a lesser work is done for transition economies. Studying transition markets is an important task as these markets become more integrated with global equity markets and attract international investors hoping to benefit from abnormal high returns as well as portfolio risk diversification. In recent years, predictability and efficiency of transition markets have attracted interest of financial economists (e.g., Emerson *et al*., 1997; Dockery and Vergari, 1997; Liu *et al*., 1997; Zalewska-Mitura and Hall, 1999; Rockinger and Urga, 2001; Harrison and Paton, 2004; Cajueiro and Tabak, 2006). Notwithstanding the fact that these markets attract a growing interest of economists in recent years, no consensus on whether or not efficient market hypothesis holds for these markets is attained yet. A common feature of these studies is that possible nonlinearities in conditional mean of the series have not been taken into account in testing efficiency of these markets. However, it is well known that many economic and financial time series follow nonlinear processes (e.g., Granger and Teräsvirta, 1993; Franses and van Dijk, 2000). Therefore, possible nonlinearities in data generating process should explicitly be taken into account in analysing financial time series in order to avoid spurious results.

The economic theory suggests a number of sources of nonlinearity in the financial data. One of the most frequently citied reasons of nonlinear adjustment is presence of market frictions and transaction costs. Existence of bid-ask spread, short selling and borrowing constraint and other transaction costs render arbitrage unprofitable for small deviations from the fundamental equilibrium. Subsequent reversion to the equilibrium, therefore, takes place only when the deviations from the equilibrium price are large, and thus arbitrage activities are profitable. Consequently, the dynamic behaviour of returns will differ according to the size of the deviation from equilibrium, irrespective of the sign of disequilibrium, giving rise to asymmetric dynamics for returns of differing size (e.g., Dumas, 1992; Shleifer, 2000). In addition to transaction costs and market frictions, interaction of heterogeneous agents (e.g., Hong and Stein, 1999; Shleifer, 2000), diversity in agents' beliefs (e.g., Brock and Hommes, 1998) also may lead to persistent deviations from the fundamental equilibrium.

Recent developments in nonlinear time series analysis allow modelling financial time series more appropriately (e.g., Granger and Teräsvirta, 1993; Franses and van Dijk, 2000). If dynamics of the market differ according to the size of deviations from equilibrium as the economic theory suggests, then such nonlinearities are more aptly modelled by an exponential smooth transition autoregressive (ESTAR) model, a class of smooth transition autoregressive (STAR) models popularised by Granger and Teräsvirta (1993) and Teräsvirta (1994). ESTAR models have extensively been used in empirical literature to test nonlinear mean reversion of financial time series, mainly for testing purchasing power parity (see, inter alia, Michael *et al*., 1997; Peel and Taylor, 2002; Taylor *et. al*, 2001; Gallagher and Taylor, 2001). Recently Kapetanios *et al*. (2003) have developed a unit root test procedure in an ESTAR framework, which has a better power than conventional Dickey-Fuller test. In this paper we apply Kapetanios *et al.* (2003) nonlinear unit root test to eight transition markets, namely, Bulgarian, Chinese, Czech, Hungarian, Polish, Romanian, Russian and Slovakian stock price indices to test whether the series contain unit root. To provide basis for comparing the results of nonlinear unit root tests to the unit root tests that do not take account of nonlinearity in the series, we also carried out two widely used unit root tests, namely, the ADF and PP tests. The ADF and PP tests suggest that all but Russian and Chinese markets contain a unit root. The results for the latter markets are mixed, however. On the other hand, the nonlinear unit root tests failed to reject the null hypothesis of unit root only in case of Bulgarian, Czech, Hungarian and Slovakian stock markets, consistent with weak form efficiency.

The remaining of the paper is organised as follows. In section 2 we describe the test procedure. In section 3 we provide estimation results, and section 4 concludes.

2. Methodology

In this section we briefly discuss the nonlinear unit root test procedure developed by Kapetanios *et al.* (2003). Consider a univariate smooth transition autoregressive (STAR) [1] model of order 1:

---

[1] For a thorough discussion of STAR models see Granger and Teräsvirta, (1993) and Teräsvirta, (1994).

$$y_t = \beta y_{t-1} + \gamma y_{t-1} F(\theta; y_{t-d}) + \varepsilon_t\,, \tag{1}$$

where y_t is a mean zero stochastic process for t = 1,…,T, $\varepsilon_t \sim iid(0,\sigma^2)$, and β and γ are unknown parameters. The transition function $F(\theta; y_{t-}\ )$ is assumed to be of the exponential form:

$$F(\theta; y_{t-d}) = 1 - \exp(-\theta y^2_{\text{t-d}})\,, \tag{2}$$

where it is assumed that $\theta > 0$, and $d \geq 1$ is the delay parameter. The exponential function is bounded between zero and one, and is symmetrically U-shaped around zero. The parameter θ is slope coefficient and determines the speed of transition between to regimes that correspond to extreme values of the transition function. Using (2) in (1) one obtains the following exponential STAR (ESTAR) model:

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left[1 - \exp(-\theta y^2_{t-d})\right] + \varepsilon_t\,, \tag{3}$$

which after reparameterising can be written conveniently as

$$\Delta y_t = \phi y_{t-1} + \gamma y_{t-1}\left[1 - \exp(-\theta y^2_{t-d})\right] + \varepsilon_t\,, \tag{4}$$

where $\phi = \beta - 1$. The ESTAR model has a nice property that it allows modelling different dynamics of series depending on the size of the deviations from the fundamental equilibrium (e.g., Teräsvirta and Anderson, 1992). As briefly discussed above, the arbitrageurs shall not engage in reversion strategies if deviations from the equilibrium are small in size and therefore arbitrage is not profitable. If the deviations from equilibrium are large enough, however, arbitrageurs shall engage in profitable reversion trading strategies, and thus bring the prices to their equilibrium levels. In the context of ESTAR model, this would imply that while $\phi \geq 0$ is possible, one must have $\gamma < 0$ and $\phi + \gamma < 0$ for the process to be globally stationary. Under these conditions, the process might display unit root for small values of y^2_{t-d}, but for larger values of y^2_{t-d} it has stable dynamics, and as a result, is geometrically ergodic. As shown by Kapetanios *et al.* (2003), ADF test may not be very powerful when the true process is nonlinear yet globally stationary.

Imposing $\phi = 0$ (which implies that y_t follows a unit root in the middle regime) the ESTAR model can be written as

$$\Delta y_t = \gamma y_{t-1}\left[1 - \exp(-\theta y^2_{t-d})\right] + \varepsilon_t\,, \tag{5}$$

The global stationarity of the process y_t can be established by testing the null hypothesis $H_0 : \theta = 0$ against the alternative $H_1 : \theta > 0$. However, testing the null hypothesis directly is not feasible since the parameter γ is not identified under the null. To overcome this problem, Kapetanios *et al.* (2003) follow suggestion of Luukkonen *et al.* (1988) to replace the transition function by its appropriate Taylor approximation to derive a t-type test statistic. Replacing the transition function with its first order Taylor approximation yields the following auxiliary regression:

$$\Delta y_t = \delta y_{t-d}^3 + e_t \,, \tag{6}$$

where e_t comprises original shocks ε_t as well as the error term resulting from Taylor approximation. The test statistic for $\delta = 0$ against $\delta < 0$ is obtained as follows:

$$t_{NL} = \hat{\delta} / s.e.(\hat{\delta}) \,, \tag{7}$$

where $\hat{\delta}$ is the OLS estimate and s.e.($\hat{\delta}$) is the standard error of $\hat{\delta}$.

To accommodate stochastic processes with nonzero means and/or linear deterministic trends, one needs following modifications. In the case where the data has nonzero mean, i.e., $x_t = \mu + y_t$, one must replace the raw data with de-meaned data $y_t = x_t - \bar{x}$ where $\bar{x}$ is the sample mean. In the case where the data has a nonzero mean and a nonzero linear trend, i.e., $x_t = \mu + \alpha t + y_t$, one must instead use the de-meaned and de-trended data $y_t = x_t - \hat{\mu} - \hat{\alpha} t$ where $\hat{\mu}$ and $\hat{\alpha}$ are OLS estimators of μ and α .

In the more general case where errors in (5) are serially correlated, one may extend (5) to

$$\Delta y_t = \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + \gamma y_{t-1}\left[1 - \exp(-\theta y_{t-d}^2)\right] + \varepsilon_t \tag{8}$$

The t_{NL} statistic for testing $\theta = 0$ in this case is given by the same expression as in (7), where $\hat{\delta}$ is the OLS estimate and s.e.($\hat{\delta}$) is the standard error of $\hat{\delta}$ obtained from the following auxiliary regression with *p* augmentations:

$$\Delta y_t = \sum_{j=1}^{p} \rho_j \Delta y_{t-j} + \delta y_{t-d}^3 + e_t \tag{9}$$

In practice, the number of augmentations *p* and the delay parameter *d* must be selected prior to the test. Kapetanios *et al.* (2003) propose that standard model selection criteria or significance testing procedure be used for selecting the number of augmentations *p*. They also suggest that the delay parameter *d* be chosen to maximize goodness of fit over $d = \{1,2,...,d_{\max}\}$.

3. Data and Unit Root Test Results

We apply the above described procedure to test whether stock prices of major transition markets contain unit root. A finding of unit root would imply that stock prices are random walk processes, and thus, weak form efficient. The investigated markets are Bulgarian, Chinese, Czech, Hungarian, Polish, Romanian, Russian and Slovakian markets. The data are monthly and sourced from Datastream. Series names, periods, and Datastream codes for the data are provided in Table 1.

Table 1
Description of Stock Price Series

Country	Series	Datastream Code	Period covered	Number of observations
Bulgaria	BSE Sofia Lazard	BSLAZ10	1997:12 – 2004:10	83
China	China A	TOTMKCA	1991:08 – 2005:12	173
Czech Republic	Total Market PI	TOTMKCZ	1993:11 – 2005:12	146
Hungary	BUX	BUXINDX	1991.01 – 2005.12	180
Poland	Total Market PI	TOTMKPO	1994:03 – 2005:12	142
Romania	Total Market PI	TOTMKRM	1996:12 - 2005:12	109
Russia	AKM Composite	RSAKMCO	1993:09 - 2005:12	148
Slovakia	SAX16	SXSAX12	1994:03 - 2005:12	142

It is well known that stock prices may contain time trend (see, for example, Beechey *et al.,* 2000). If the market is efficient, however, fluctuations in the stock prices away from trend should be unpredictable. Therefore, in conducting the above described nonlinear unit root test we consider de-meaned and de-trended series. The de-meaned and de-trended series were obtained by regressing the natural logarithms of index series on a constant and a linear time trend.

Preliminary tests for nonstationarity of the series and their differences, based on ADF (Dickey and Fuller, 1981) and PP (Phillips and Perron, 1988) tests are provided in Table 1. Both tests suggest that all but Russian and Chinese stock price indices are *I(1)* processes, consistent with the efficient market hypothesis. For the latter two markets, ADF and PP tests provide mixed results. The ADF test rejects the null hypothesis of unit root for Russian stock price series at 5% significance level whereas the PP test indicates presence of a unit root. For the Chinese stock market, the ADF test does not reject the null hypothesis of unit root while the PP test rejects the unit root at 5% significance level.

Table 2
Linear Unit Root Test Results

	ADF		PP	
Country	Log Level[a]	First Difference[b]	Log Level[a]	First Difference[b]
Bulgaria	-0.822	-12.489*	-0.695	-11.937*
China	-1.606	-4.601*	-3.505**	-14.387*
Czech Republic	-0.933	-10.120*	-0.944	-10.025*
Hungary	-1.872	-12.428*	-1.937	-12.429*
Poland	-2.755	-13.524*	-2.691	-13.566*
Romania	-1.702	-9.705*	-2.075	-9.714*
Russia	-3.854**	-9.260*	-3.400	-9.290*
Slovakia	-0.510	-8.277*	-0.813	-7.942*

Notes:
a) Regressions include an intercept and linear time trend.
b) Regressions include only intercept.
Optimal lag length in ADF test was selected using AIC with maximum lag order of 12. * and ** indicate significance at 1% and 5% significance levels, respectively.

To carry out the nonlinear unit root tests, we firstly estimated an AR(12) model for each series and excluded insignificant (at 10% significance level) augmentation terms. Then, we estimated regression (9) with selected augmentations to compute the t_{NL} statistics[2]. We selected the delay parameter d that maximised R^2 over $d = \{1,2,...,12\}$. Unlike the case of testing linearity against STAR type nonlinearity, the t_{NL} test does not have an asymptotic standard normal distribution. Therefore, we bootstrapped the t_{NL} test statistic with 10,000 replications. We also estimated the ESTAR model as given in (8). Initial estimates of γ found to be poorly identified, a result that has been observed elsewhere (e.g., Taylor *et al.*, 2001; Kapetanios *et al.*, 2003). Therefore, following previous researchers, we set γ to minus unity. The test statistics and estimation results are provided in Table 3.

---

[2] To save space, we do not provide estimates of AR models and of the regression (9) here. These estimates as well as the estimates of the augmentation terms in regression (8) are available upon request. In estimating ESTAR models, following previous researchers, we divided slope coefficients θ by sample variance of the transition variable to standardise the transition parameter.

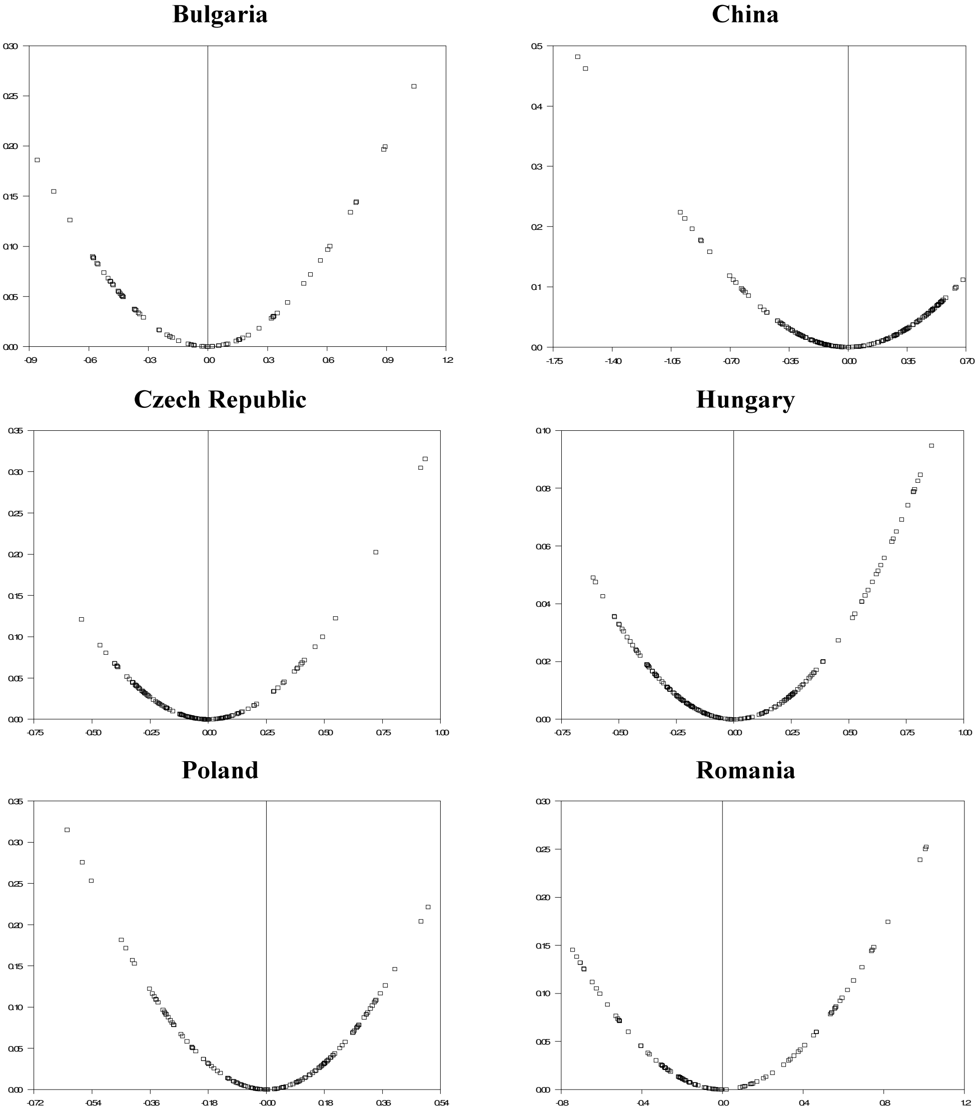
Table 3
Nonlinear Unit Root Test Results

Country	t_{NL}	$\hat{\theta}$	Standard error of $\hat{\theta}$
Bulgaria	-2.761	0.053	0.033
China	-4.533*	0.046**	0.020
Czech Republic	-3.042	0.029	0.017
Hungary	-2.261	0.017	0.010
Poland	-4.500*	0.054*	0.019
Romania	-3.488**	0.052*	0.014
Russia	-3.653**	0.032*	0.008
Slovakia	-1.256	0.011	0.007

Notes: The t_{NL} statistic was computed by bootstrapping with 10,000 replications. Asymptotic critical values of the t_{NL} statistic at 1%, 5% and 10% significance levels are -3.93, -3.40 and -3.13. These values are taken from Table 1, Kapetanios et al. (2003, p. 364). * and ** denote significance at 1% and 5% levels, respectively.

As the Table 3 reveals, the null hypothesis of unit root is rejected at 1% significance level for Chinese and Polish series and at 5% for the Russian and Romanian series, suggesting that these markets are not efficient. The null of unit root is not rejected at conventional levels for the Bulgarian, Czech, Hungarian and Slovakian series, however, implying that these markets are weak form efficient. It is interesting to note that whenever null hypothesis of unit root is rejected at either 1% or 5% levels, the estimate of θ is also significant, verifying mean reversion for these stock price series. This is an expected result since under the null hypothesis that $\theta = 0$, each of the stock price series follows a unit root process.

Fig. 1. Scatter of Estimated Transition Functions Against Transition Variable y_{t-d}



Bulgaria

China

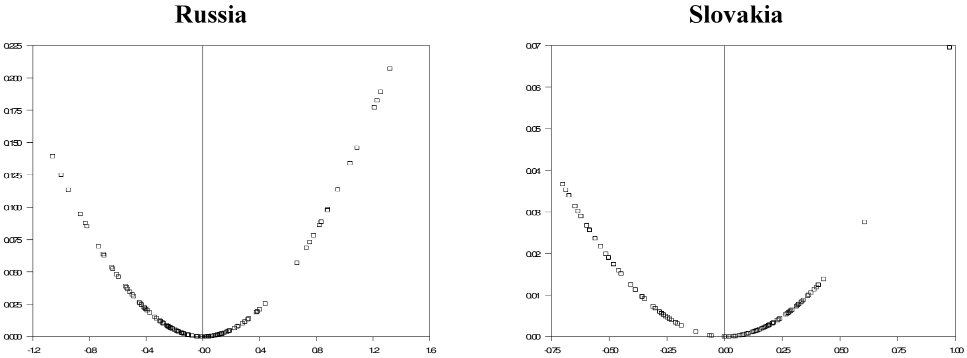
Czech Republic

Hungary

Poland

Romania

Fig. 1. Scatter of Estimated Transition Functions Against Transition Variable y_{t-d} *(continued)*



Russia

Slovakia

In Figure 1 we provide plots of each of the estimated transition functions against the corresponding transition variable for each of the series. The estimated slope coefficients indicate that the speed of transition is weak suggesting that stock prices are characterised by slow yet significant reversion to long-run equilibrium levels. As pointed out by Sarno (2000), low speed of mean reversion is consistent with the difficulty of rejecting the null hypothesis of unit root using conventional linear nonstationarity tests.

4. Conclusion

In this paper we have tested whether Bulgarian, Chinese, Czech, Hungarian, Polish, Romanian, Russian and Slovakian stock price series contain unit root, consistent with weak form efficiency. For this purpose we carried out conventional ADF and PP unit root tests as well as nonlinear unit root test recently proposed by Kapetanios *et al.* (2003). The results of ADF and PP indicate that Bulgarian, Czech, Hungarian, Polish, Romanian and Slovakian stock price series contain unit root. However, ADF and PP tests provide mixed results for Chinese and Russian price series. Using nonlinear unit root test due to Kapetanios *et al*. (2003), we are able to reject the null hypothesis of unit root for Chinese, Polish, Romanian and Russian stock price series, implying that these markets are not weak form efficient. Estimated ESTAR models also support the results of nonlinear unit root tests; whenever the null hypothesis of unit root is rejected, slope coefficients of the ESTAR models found to be statistically significant, indicating that the price series indeed are mean reverting. Moreover, estimated slope coefficients indicate slower mean reversion than one would anticipate for large variations in prices, explaining why conventional unit root tests fail detect global stationarity.

References

Beechey, M., Gruen, D. and Vickery, J. The Efficient Market Hypothesis: A Survey, *Reserve Bank of Australia,* Research Discussion Paper No: 2000-01.

Brock, W.A. and Hommes, C.H. Heterogeneous Beliefs and Routes to Chaos in A Simple Asset Pricing Model, *Journal of Economic Dynamics and Control* 22, (1998): 1235-1274.

Cajueiro, D.O. and Tabak, B.M. Testing for Predictability in Equity Returns for European Transition Markets, *Economic Systems* 30, (2006): 56-78.

Chaudhuri, K. and Wu, Y. Random Walk Versus Breaking Trend in Stock Prices: Evidence From Emerging Markets, *Journal of Banking and Finance* 27, (2003): 575–92.

Dickey, D.A. and Fuller, W.A. Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root, *Econometrica* 49, (1981): 1057–72.

Dockery, E. and Vergari, F. Testing the Random Walk Hypothesis: Evidence for the Budapest Stock Exchange, *Applied Economics Letters*, 4 (1997): 627-29.

Dumas, B. Dynamic Equilibrium and the Real Exchange Rate in a Spatially Separated World, *Review of Financial Studies* 5, (1992): 153–180.

Emerson, R., Hall, S.G. and Zalewska-Mitura, A. Evolving Market Efficiency with an Application to Some Bulgarian Shares, *Economics of Planning* 30, (1997): 75–90.

Fama, E.F. Efficient Capital Markets: A Review and Empirical Work, *Journal of Finance* 25, (1970): 383-417.

——— Efficient Capital Markets: II, *Journal of Finance* 46, (1991): 1575- 617.

Franses, P.H. and van Dijk, D., *Non-Linear Time Series Models in Empirical Finance*, Cambridge University Press, 2000.

Gallagher, L. and Taylor M.P. Risky Arbitrage, Limits of Arbitrage and Nonlinear Adjustment in the Dividend-Price Ratio, *Economic Inquiry* 39, (2001): 524-36.

Granger, C.W.S. and Teräsvirta, T., *Modelling Nonlinear Economic Relationships*, Oxford University Press, 1993.

Grieb, T.A. and Reyes, M.G. Random Walk Tests for Latin American Equity Indexes and Individual Firms, *Journal of Financial Research* 22, (1999): 371–83.

Harrison B. and Paton, D. Transition, the Evolution of Stock Market Efficiency and Entry into EU: The Case of Romania, *Economics of Planning* 37, (2004): 203-23

Hong, H. and Stein, J.C. A Unified Theory of Under-reaction, Momentum Trading, and Over-reaction in Asset Markets, *Journal of Finance* 54, (1999): 2143–84.

Kapetanios, G., Shin, Y. and Snell, A. Testing For a Unit Root in the Nonlinear Star Framework, *Journal of Econometrics* 112, (2003): 359-79.

Liu, X., Song, H. and Romilly, P. Are Chinese Stock Markets Efficient? A Cointegration and Causality Analysis, *Applied Economics Letters* 4, (1997): 511–5.

Lo, A.W. and MacKinlay, A.C. Stock Market Prices Do not Follow Random Walks: Evidence From a Simple Specification Test, *Review of Financial Studies* 1, (1988): 41- 66.

Luukkonen, R., Saikkonen, P. and Teräsvirta, T. Testing Linearity Against Smooth Transition Autoregressive Models, *Biometrika* 75, (1988): 491-99.

Michael, P., Nobay, R.A. and Peel, D.A. Transaction Costs and Nonlinear Adjustment in Real Exchange Rates: An Empirical Investigation, *Journal of Political Economy* 105, (1997): 862-79.

Peel, D.A. and Taylor, M.P. Covered Interest Rate Arbitrage in the Interior Period and the Keynes-Einzig Conjecture, *Journal of Money, Credit and Banking* 34, (2002): 51-75.

Phillips P.C.B. and Perron, P. Testing For Unit Roots: In Time Series Regression, *Biometrica* 75, (1988): 335-46.

Rockinger, M. and Urga, G. A Time Varying Parameter Model to Test for Predictability and Integration in Stock Markets of Transition Economies, *Journal of Business & Economic Statistics* 19, (2001): 73-84.

Sarno, L. Real Exchange Rate Behaviour in High Inflation Countries: Empirical Evidence from Turkey, 1980-1997, *Applied Economics Letters* 7, (2000): 285-91.

Shleifer, A. *Inefficient Markets: An Introduction to Behavioural Finance,* Clarendon Lectures in Economics: Oxford University Press, Oxford 2000.

Taylor, M.P., Peel, D.A. and Sarno, L. Nonlinear Mean-Reversion in Real Exchange Rates: Towards a Solution to the Purchasing Power Parity Puzzles, *International Economic Review* 42, (2001): 1015–42.

Teräsvirta, T. Specification, Estimation, and Evaluation of Smooth Transition Autoregressive Models, *Journal of the American Statistical Association* 89, (1994): 208-18.

Teräsvirta, T. and Anderson, H. Characterizing Nonlinearities in Business Cycles Using Smooth Transition Autoregressive Models. Journal of Applied Econometrics 7, (1992): 11-36.

Zalewska-Mitura, A. and Hall, S.G. Examining the First Stages of Market Performance: A Test for Evolving Market Efficiency, *Economics Letters* 64, (1999): 1-12.