LONG MEMORY IN EXCHANGE RATES: INTERNATIONAL EVIDENCE

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ABSTRACT

In this paper we test for the presence of fractional integration, or long memory, in the daily returns of exchange rates using ARFIMA(p,d,q) models. We consider 34 exchange rates against the US dollar (USD) covering the period April 1991 to April 2006. The results suggest that 17 exchange rates show strong evidence of long memory. This indicates that shocks to the exchange rates persist over a long period of time (this is stronger in emerging market economies). This also indicates that these markets are not stable, and hence they offer an opportunity to investors and traders to add some risk to their strategies. The lack of long memory in the daily returns of exchange rates supports the efficient market hypothesis (EMH). These findings are helpful to traders dealing with long dated assets.

JEL: C22, C52, G14

INTRODUCTION

It is widely believed that the logs of financial prices contain a unit root. However, some series evidently do not possess a further unit root, while they show signs of dependence. Such series are argued to possess long memory. Long memory in time series can be defined as autocorrelation at long lags, of up to hundreds of time periods (Tolvi, 2003). Under this phenomenon, systems are characterized by their ability to 'remember' events in the long history of time series data and their ability to make decisions on the basis of such memories. According to long memory hypothesis, what happens today affects the future.

Knowledge of the time series properties of exchange rates has important economic implications. The empirical analysis of exchange rates provides useful information that can be used to evaluate the performance of exchange rate models. The objectives of this paper are twofold: (i) to examine and justify the presence of long memory (via fractional integration) in the prices of foreign exchange rates, and (ii) to test the validity of time series models on the presence of long memory in exchange rates. Time series models are important for the determination of international trade flows, prices of tradable goods, prices of foreign exchange futures and options and international asset portfolios (Cheung, 1993).

A number of studies have tested the long memory hypothesis using data from mature and emerging financial markets. If asset returns display long memory, they exhibit significant autocorrelation between observations widely separated in time. The absence/presence of long-term dependence on the mean of financial-asset returns is used as a proxy for analyzing market efficiency. The presence of long memory in asset returns contradicts the weak form of the efficient market hypothesis (EMH), which states that, conditioning on historical returns, future asset returns are unpredictable (Barkoulas *et al*., 2000).

Previous studies on this issue have relied on ARIMA models and have examined only a few countries. We test for the presence of long memory, or fractional dynamics, using the framework of Autoregressive Fractionally Integrated Moving Average (ARFIMA) allowing for a more precise specification of the order of integration. We use daily data from 34 exchange rates over the US dollar. Our findings are important since no previous work has examined this hypothesis using daily data from a large sample of countries covering all five continents or has used the ARFIMA methodology. Thus this paper extends the literature on two fronts. The remainder of this paper is organized as follows: In the next section a Literature

Review is provided. This section is followed by a Methodology Section that presents the long memory methodology through ARFIMA (p,d,q) models. The following section discusses the data used in this study. Next, the empirical results are examined. The paper closes with some concluding comments.

LITERATURE REVIEW

A number of researchers examine the long memory hypothesis in exchange rates (Bhar, 2000; Gil-Alana, 2000; Laurini and Portugal, 2003). The exchange rate between two currencies specifies how much one currency is worth in terms of the other. Traditionally, it has been assumed that the exchange rates have a unit root implying that shocks have permanent effects on the series (Taylor, 1995). However, some authors suggest that the exchange rates are mean-reverting (Gil-Alana, 2000).

Lo (1991) tests for long-run memory in daily and monthly stock market indices and finds no evidence of long-range dependence. Cheung and Lai (1995) examine long memory in international stock market returns using the Morgan Stanley Capital International stock index data for eighteen countries. Their results provide little support for long memory. According to Cheung and Lai (1995), the findings are not sensitive to inflation adjustments in stock returns, data sources, and statistical methods used. Furthermore, Ding and Granger (1996) examine the long memory property for various speculative returns. They report evidence of long memory for S&P 500 returns and four other speculative returns. Recently, Gil-Alana (2006) uses parametric and semi-parametric methods to test for the order of integration (and fractional integration) in daily stock market indices: EOE, DAX, Hang Seng, FTSE100, S&P 500, CAC 40, Singapore All shares and the Japanese Nikkei. He reports that the order of integration of the Singapore All Shares and the Hang Seng is much higher than one. Furthermore, Gil-Alana (2006) finds conclusive evidence against mean reversion, but long memory on their returns. For S&P 500, the fractional integration (long-memory) parameter is below one, while for the remaining series the values oscillate around the unit root. Barkoulas *et al*. (2000) test for the presence of long memory in the return series for the Greek stock market (an emerging capital market). They find significant and robust evidence of positive long-term persistence. In addition, Tolvi (2003) tests the long memory hypothesis in Finnish stock market, while Vougas (2004) extends the work of Barkoulas *et al*. (2000). He analyzes long memory and volatility of returns in the Athens Stock Exchange and finds weaker evidence in favour of long memory.

Cheung (1993) finds evidence of long memory in exchange rate data. Bhar (2000) examines long memory in the Yen/dollar rate. He finds no evidence of long memory indicating efficient pricing by the market participants. Cheng (2001) examines the long memory dynamics in the daily and weekly rates of six Asia Pacific countries. His findings reveal strong evidence of long memory in the weekly series. Laurini and Portugal (2003) show that the evidence of long memory for the daily R$/US$ series after the implementation of the Rate Plan is not robust. Furthermore, Gil-Alana (2004) shows that exchange rates series have a component of long memory behaviour. Recently, Soofi *et al*. (2006) use the plug-in and Whittle methods (spectral regression analysis) to test for the long memory property in 12 Asian/dollar daily exchange rates. Their findings, based on the two different methods, are mixed.

METHODOLOGY

Previous studies used the standard Integrated Autoregressive Moving Average (ARIMA) model to study the intertemporal dynamics of exchange rates. An integrated series of order d must be differenced d times before it can be represented by a stationary and invertible ARMA process. If this ARMA representation is of order (p,q) then the original, undifferenced series is following an ARIMA(p,d,q) representation.

This paper examines the dynamics of exchange rates in the fractionally integrated autoregressive moving average (ARFIMA) framework which is a generalization of the ARIMA(p,d,q) model. The ARFIMA model is the generalization of the concept of the order of integration used in ARIMA models, thus allowing the order of integration to be a fractional number (Laurini and Portugal, 2004). We test ARFIMA(p,d,q) models via conditional maximum likelihood (ML), following the recent work of Vougas (2004). For the returns series r_t, where $t = 1,...,T$, the ARFIMA model is given by:

$$\phi(L)(1-L)^d (r_t - \mu) = \theta(L)\varepsilon_t \qquad (1)$$

L is the lag operator ($L^j r_t = r_{t-j}$ $L)(1-L)^d (r_t - \mu) = \theta(L)\varepsilon_t$ is the autoregressive polynomial, and $\theta(L) = 1 + \theta_1 L + ... + \theta_q L^q$ s the moving average polynomial. The differencing parameter *d* is not necessarily an integer (it takes real values), but integer values of *d* lead to the traditional ARIMA model. Therefore, the fractional differencing parameter $(1-L)^d$ can be defined for non-integer values by the following binomial expansion:

$$(1-L)^d = \sum_{j=0}^{\infty} \binom{d}{j} (-L)^j \qquad (2)$$

We also make the assumptions that (i) the residuals $\varepsilon_t \sim NID(0, \sigma_t^2)$ and (ii) the roots of the AR and MA parameters fall outside the unit circle and do not have common roots. Significance of *d* parameter is evidence of long memory. When *d* parameter has values greater or equal to 0.5, the series does not have stationary covariance, and consequently it has infinite covariance as shown by Baillie *et al*. (1996). When *d* is between 0 and 0.5, the lag length increases the autocorrelations decay hyperbolically to zero, while when *d* = 0, decays exponentially to zero. If *d* is between -0.5 and 0, then it is usually identified as having intermediate memory, since autocorrelations are always negative. Further, we need to select a parsimonious ARFIMA(*p,d,q*) model using two information criteria: the Akaike (AIC) and Schwarz (SBC). The information criteria are given by:

$$\begin{aligned} AIC &= -2(\hat{\ell}/n) + (2(p+q+2))/n \\ SBC &= -2(\hat{\ell}/n) + ((p+q+2)\ln(n))/n \end{aligned} \qquad (3)$$

where $\hat{\ell}$ is the value of the maximized likelihood. The best (selected) model has the smallest AIC or SBC value. It is known that AIC always selects a generously parameterized model, while SBC selects a less generously parameterized model (Vougas, 2004). In general, the AIC is one of the most commonly used in time series analysis. The selected ARFIMA model is a parsimonious and flexible model that can be used to study long memory and short-run dynamics simultaneously. Fractional integration is a more general way to describe long-range dependence than the unit-root specification and provides an alternative perspective to examine the unit-root hypothesis (Cheung, 1993).

Data Description

Foreign exchange markets are rather different from most financial markets. The vast bulk of trading takes place between professional foreign exchange dealers of banks. They do not meet the people they are trading with face to face, but they do their transactions over the phone or electronically. Note that foreign exchange markets are particularly rich on noise traders.

The structure of this market has two interesting implications: (i) exchange rates are moved by news. Since news is random and unpredictable, exchange rates will tend to move in a random way, and (ii) in the foreign exchange markets, there are not active cross-markets between all parts of currencies, but this does not matter, because all currencies that have a market at all have one with the US dollar. Hence, the US dollar can be thought of as the medium of exchange of the foreign exchange markets.

The data covers the period from April 1991 to April 2006, and the main source is the Datastream International. We consider daily exchange rates from 34 countries (the total number of observations vary from 1397 to 3915), as follows: Europe (Czech Republic, Cyprus, Denmark, Hungary, Norway, Poland and UK), Asia (Bahrain, Hong Kong, India, Israel, Japan, Kuwait, Lebanon, Malaysia, Oman, Philippines, Russia, Singapore, South Korea, Sri Lanka and Turkey), Africa (Botswana, Egypt, Kenya, Mauritius, Morocco and Tunisia), America (Argentina, Canada, Mexico, Uruguay and Venezuela) and Australia. The empirical analysis is based on both developed and developing (or emerging) markets. Note that emerging countries constitute approximately 80% of the global population, representing about 20% of the world's economies (worldbank.com).

Table 1 presents the descriptive statistics for the log-exchange rates. Most series show positive skewness (the distribution is skewed to the right), while the distribution is peaked (leptokurtic) for Bahrain, Lebanon and Oman and flat (platykurtic) relative to normal for the rest. We also reject the hypothesis of normal distribution at the 5% level (for all series). The ADF tests show evidence of non-stationarity, I (1), for all series (the results are not reported here).

Table 1: Descriptive Statistics for Log-exchange Rates over the US Dollar

Country	Obs.	Mean	S.d.	Skewness	Kurtosis	Normality
Argentina	3915	-0.3	0.49	-1.01	-0.914	7358 (0.00*)
Australia	3915	-0.38	0.13	-0.78	-0.53	1540 (0.00*)
Bahrain	3915	0.97	0.0012	-9.6276	467.35	43410 (0.0*)
Botswana	3200	-1.45	0.27	0.44	-0.87	508 (0.00*)
Canada	3915	-0.313	0.094	0.298	-0.815	323 (0.00*)
Cyprus	1397	0.628	0.139	-0.3178	-1.4159	386 (0.00*)
Czech Re.	3740	-3.39	0.147	-0.389	-0.769	409 (0.00*)
Denmark	3915	-1.88	0.123	-0.633	-0.393	713 (0.00*)
Egypt	1397	-1.655	0.169	0.578	-1.209	620 (0.00*)
Hong Kong	3915	-2.0492	0.0035	-0.269	-1.4925	1120 (0.00*)
Hungary	3740	-5.16	0.412	0.683	-0.787	1347 (0.00*)
India	3915	-3.64	0.207	0.731	-0.344	1013 (0.00*)
Israel	3915	-1.279	0.2266	0.50474	-0.98699	944 (0.00*)
Japan	3915	-4.741	0.1021	0.29175	0.32928	54.5 (0.00*)
Kenya	1397	-4.3481	0.0308	0.9155	0.6655	306 (0.00*)
Kuwait	3915	1.205	0.01884	0.4014	-0.64159	363 (0.00*)
Lebanon	3915	-7.3244	0.15394	1.8736	6.6586	1824 (0.00*)
Malaysia	3915	-1.1674	0.19495	0.28252	-1.8101	2570 (0.00*)
Mauritius	1397	-3.3619	0.04427	0.77599	0.34759	220 (0.00*)
Mexico	3915	-1.9514	0.48526	0.89259	-0.89499	3684 (0.00*)
Morocco	1397	-2.2861	0.10878	-0.32073	-1.3311	330 (0.00*)
Norway	3915	-1.9694	0.11723	-0.63968	-0.35334	698 (0.00*)
Oman	1397	0.95477	0.00147	2.3933	6.7964	2582 (0.00*)
Philippines	3915	-3.6109	0.32409	0.012577	-1.7227	1372 (0.00*)
Poland	3740	-1.0961	0.35652	1.1464	0.4519	2342 (0.00*)
Russia	1397	-3.3856	0.043161	-0.3789	-1.1515	283 (0.00*)
Singapore	3915	-0.48963	0.078495	0.71816	-0.59781	1277 (0.00*)
South Korea	3915	-6.9066	0.21657	-0.0916	-1.301	539 (0.00*)
Sri Lanka	1397	-4.5698	0.05347	0.93817	0.82954	297 (0.00*)
Tunisia	1397	-0.2929	0.0634	-0.16369	-1.1314	147 (0.00*)
Turkey	3915	1.7043	1.99	0.5	-1.1419	1185 (0.00*)
UK	3915	0.48072	0.078546	0.36253	-0.53742	253 (0.00*)
Uruguay	3915	-2.2933	0.76255	0.27532	-0.79199	280 (0.00*)
Venezuela	3915	-6.0992	1.1483	0.37894	-1.0415	655 (0.00*)

*This Table shows the summary statistics for log-exchange rates. Skewness is a measure of asymmetry of the distribution of the series around its mean. Kurtosis measures the peakedness or flatness of the distribution of the series. Normality (under Jarque-Bera test) is a test statistic for testing whether the series is normally distributed (probability value is in parentheses). * indicates significance at the 5% level.*

EMPIRICAL RESULTS

We use the ARFIMA framework which allows for long memory in the data. ARFIMA(p,d.q) models are estimated via conditional Maximum Likelihood (ML) using the Ox language (PcGive software). We run various ARFIMA(p,d,q) specifications with $p+q \leq 2$ (not reported here). There is evidence of unit roots, and the selected ARFIMA model, for all samples, is ARFIMA(1,d,1). The selected ARFIMA(1,d,1) model corresponds to the smallest AIC and SBC information criteria.

The results from Europe are reported in Table 2 (Panel A). Accordingly, all models show insignificant *d* parameter. Hence, the results from the European/$US rates show weak evidence of long memory. The results for Africa (Table 2 – Panel B) show that four rates (Botswana, Egypt, Kenya and Mauritius) support the long memory hypothesis. Similarly, the results for Asian countries (Table 2 – Panel C) show evidence of long memory for ten countries (Bahrain, Hong Kong, India, Israel, Lebanon, Oman, Philippines, Russia, South Korea and Turkey). However the evidence for America and Australia is mixed. Table 2 – Panel D shows that only three rates (Argentina, Mexico and Uruguay) have long memory properties, with the remaining countries not showing the presence of long memory.

Furthermore, Figure 1 presents the variation of *d* parameter for all countries which support the long memory hypothesis. The results from Africa and Asian countries (Figures 1.1-1.2) show that $-0.1643< d_{africa} < 0.3741$ and $-0.947< d_{aasian} <0.3649$, while for America (Figure 1.3) $0.144< d_{america} <0.2816$. More specific, for American exchange rates (Argentina, Mexico and Uruguay), empirical evidence shows that the lag length increases the autocorrelations decay hyperbolically to zero. This is also true for African exchange rates (Botswana, Egypt and Mauritius). The only exception is Kenya; there is evidence of intermediate memory, since autocorrelations are always negative. Finally, for the Asian/$US rates, the empirical evidence is mixed. Five exchange rates (India, Israel, Lebanon, Russia and Turkey) support the property that the lag length increases the autocorrelations decay hyperbolically to zero. In addition, five Asian/$US exchange rates (Bahrain, Hong Kong, Oman, Philippines and South Korea) show evidence of intermediate memory, since autocorrelations are always negative.

Table 2: Empirical Results

PANEL A. ML Estimation of ARFIMA(1,d,1) Models: EUROPE

COUNTRY	ϕ_1	θ_1	*d*	*AIC*	*LL*
Czech Rep	-0.138 (-0.9)	0.013 (0.08)	0.006 (0.247)	-6.9930	13078.7000
Cyprus	-0.49 (-1.22)	0.41 (0.94)	-0.029 (-0.9)	-7.1880	5021.3000
Denmark	0.04 (0.0534)	-0.07 (-0.09)	-0.00012 (-0.0048)	-7.2260	14145.4000
Hungary	-0.1866 (-1.43)	0.037 (0.264)	-0.0036 (-0.184)	-6.9790	13051.9000
Norway	0.2318 (0.1)	-0.239 (-0.104)	-0.0305 (-1.08)	-7.1205	13938.9000
Poland	-0.0971 (-2.21)*	-0.35 (-5.88)*	0.043 (1.61)	-6.3411	11858.7400
UK	0.5597 (0.6)	-0.5143 (-0.576)	-0.020 (-0.249)	-7.5624	14803.5200

* Significant at 5% Level

PANEL B. ML Estimation of ARFIMA(1,d,1) Models: AFRICA

COUNTRY	ϕ_1	θ_1	*d*	*AIC*	*LL*
Botswana	0.398 (4.27)*	-0.56 (-5.15)*	0.085 (1.90)*	-6.9700	11159.7000
Egypt	0.182 (2.22)*	-0.486 (-4.63)*	0.13 (2.3)*	-7.2899	5092.3600
Kenya	0.1478 (1.1)	0.04 (0.346)	-0.1643 (-4.56)*	-8.0474	5621.1300
Mauritius	-0.1615 (-4.4)*	-0.737 (-18.1)*	0.3741 (6.63)*	-8.1154	5668.5700
Morocco	-0.4215 (-1.34)	0.3466 (1.03)	-0.00323 (-0.11)	-7.7020	5380.3500
Tunisia	0.1354 (1.21)	-0.3642 (-2.65)*	0.01316 (0.241)	-7.5351	5263.5500

* Significant at 5% Level

PANEL C. ML Estimation of ARFIMA(1,d,1) Models: ASIA

COUNTRY	ϕ_1	θ_1	*d*	*AIC*	*LL*
Bahrain	0.175 (2.56)*	0.139 (2.61)*	-0.947 (-37.5)*	-10.6000	20754.5000
Hong Kong	-0.153 (-1.14)	-0.0196 (-0.127)	-0.156 (-5.7)*	-12.5390	24544.5000
India	0.45 (5.00)*	-0.61 (-5.81)*	0.138 (3.07)*	-8.1910	16033.9000
Israel	0.0474 (1.55)	-0.563 (-11.2)*	0.116 (2.8)*	-7.2710	14233.9000
Japan	0.0825 (0.0951)	-0.1 (-0.115)	0.0016 (0.0679)	-7.1052	13909.0700
Kuwait	0.0106 (0.199)	-0.3249 (-4.61)*	-0.0354 (-1.1)	-9.4924	18580.7000
Lebanon	0.3059 (9.40)*	-0.7177 (-20.5)*	0.3649 (7.59)*	-7.3175	14324.4500
Malaysia	-0.3849 (-3.91)*	0.2914 (2.74)*	0.0277 (1.54)	-7.4419	14567.8000
Oman	0.33192 (2.32)*	-0.465 (-3.0)*	-0.569 (-10.4)*	-10.5862	7393.1900
Philippines	-0.07 (-0.349)	0.158 (0.831)	-0.052 (-2.85)*	-7.2156	14125.1000
Russia	-0.0962 (-1.03)	-0.255 (-2.12)*	0.1062 (2.41)*	-9.3367	6521.0490
Singapore	-0.04689 (-0.26)	-0.0544 (-0.285)	0.0099 (0.410)	-8.4362	16513.6600
South Korea	0.1343 (2.1)*	0.087 (1.57)	-0.083 (-4.46)*	-6.6835	13083.7500
Sri Lanka	0.384 (2.39)*	-0.515 (-2.85)*	0.066 (1.05)	-8.5790	5992.1500
Turkey	0.432 (11.6)*	-0.8132 (-29.6)*	0.266 (5.3)*	-5.4	10571.96

* Significant at 5% Level

PANEL D. ML Estimation of ARFIMA(1,d,1) models: AMERICA & AUSTRALIA

COUNTRY	ϕ_1	θ_1	*d*	*AIC*	*LL*
Argentina	0.6604 (14.2)*	-0.80 (-25.9)*	0.179687 (3.97)*	-6.1700	12097.6700
Canada	0.079 (0.138)	-0.1 (-0.173)	-0.006 (-0.271)	-8.3590	16363.9000
Mexico	0.3946 (7.86)*	-0.605 (-10.1)*	0.144 (3.36)*	-6.5502	12822.7600
Uruguay	0.4754 (12.7)*	-0.8326 (-34.1)*	0.2816 (5.59)*	-6.7462	13206.3200
Venezuela	-0.00502 (-0.1)	-0.4157 (-6.49)*	0.0357 (1.18)	-4.4919	8794.7800
Australia	-0.296 (-0.76)	0.3179 (0.807)	-0.024 (-1.52)	-7.3514	14390.8500

* Significant at 5% Level

This Table shows the estimation of ARFIMA (1,d,q) models. LL indicates the log-likelihoods, d indicates the long memory parameter, and AIC is the Akaike information criterion. T-statistics are in parentheses.

Figure 1: The Variation of Long Memory Parameter (*d*) Across Countries

Figure 1.1: Africa (*d*) Parameter

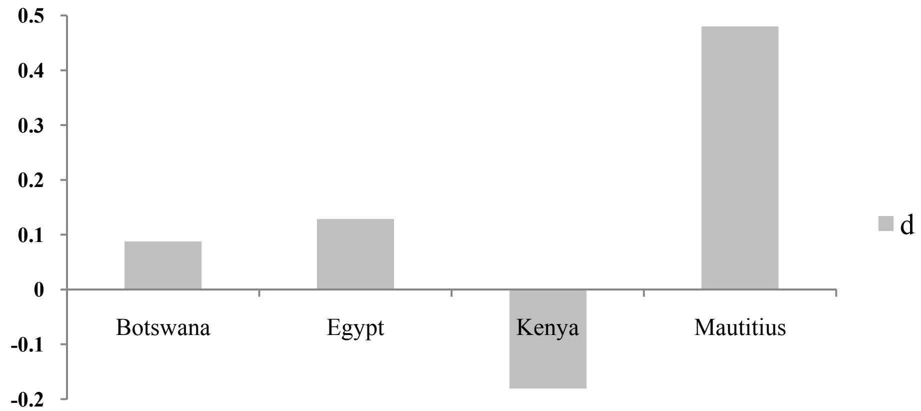

Figure 1.2: Asia (*d*) Parameter

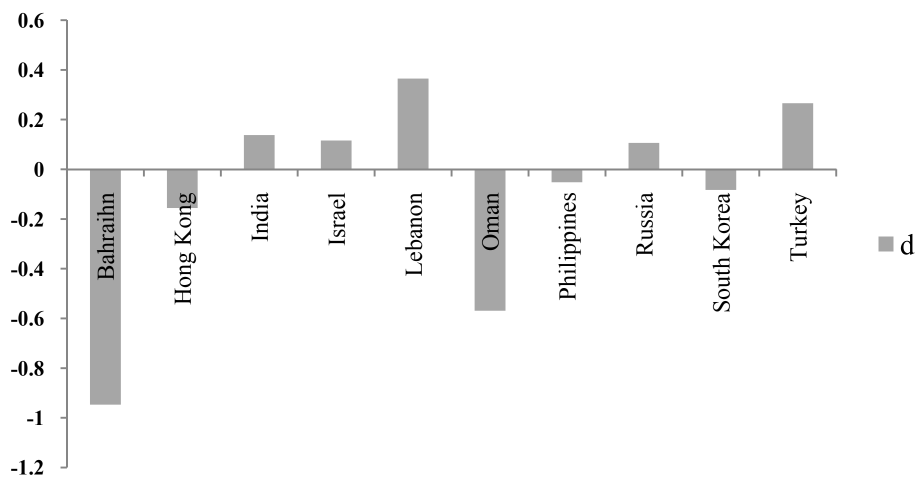

Figure 1.3: America (*d*) Parameter

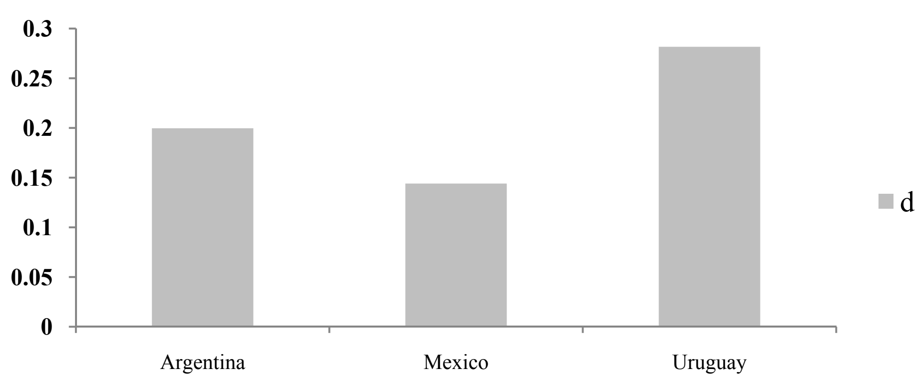

Figure 1 shows the variation of significant long memory parameter (d) across countries.

CONCLUSIONS

In this paper, conditional maximum likelihood is employed to estimate ARFIMA models and test for long memory in exchange rates. We examine the evidence of long memory in the daily exchange rates over the US dollar. Since currency trading always involves buying one currency and selling another, we consider data from 34 countries (from all five continents) covering the period April 1991 to April 2006.

The results from the selected ARFIMA(1,d,1) models show evidence of long memory in African and Asian countries. The results from the European rates show weak evidence of long memory (*d* is not significant), while the evidence from America and Australia is mixed. In general, we find that 17 exchange rates show strong evidence of long memory. This indicates that shocks to these rates persist over a long period of time. Furthermore, the long memory hypothesis is stronger in emerging market economies (economies with low-to-middle per capital income). This indicates that these transition (emerging) markets are not stable, and hence they offer an opportunity to investors and traders to add some risk to their strategies.

As an emerging market, a country should embark on an economic reform program that will lead it to stronger and more responsible economic performance levels, as well as transparency and efficiency in the capital market. An emerging market economy should reform its exchange rate system because a stable local currency builds confidence in an economy, especially when foreigners are considering investing. Exchange rate reforms also reduce the desire for local investors to send their capital abroad.

These findings are helpful to financial managers, traders and investors dealing with foreign exchange rates. Further research should (i) investigate the predictability of foreign exchange rates using ARFIMA time-series methods, and (ii) run a sensitivity analysis to ascertain the robustness and temporal stability of the long memory.

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BIOGRAPHY

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