Do Currency Regime and Developmental Stage Matter for Real Exchange Rate Volatility? A Cross-Country Analysis

Hossain, Monzur

2009

Do Currency Regime and Developmental Stage Matter for Real Exchange Rate Volatility? A Cross-Country Analysis

Monzur Hossain*
Bangladesh Institute of Development Studies (BIDS)
E-17 Agargaon, Sher-e-Bangla Nagar, Dhaka 1207
Bangladesh

* I would like to thank Kenichi Ohno, David Peel, Richard T. Baillie and other participants at the 14th annual symposium of the Society of non-linear Dynamics and Econometrics, Washington University, St. Louis, March, 2006 for their comments on the earlier version of the paper.

Do Currency Regime and Developmental Stage Matter for Real Exchange Rate Volatility?

Abstract

This paper analyzes real effective exchange rate (REER) volatility of 18 countries for the post-Bretton Woods period (1973-2004) under the Markov chain model framework. The findings can be summarized as follows: (i) flexible regimes induce higher short-term volatility; (ii) neither currency regime nor developmental stage is found to induce long-term real volatility; and (iii) flexible regimes and lower level of development can help adjust to long-term real shocks. Further investigation suggests that less developed economies adjust to long-term real shocks by deviating from their *de jure* exchange rate regime. Moreover, estimated steady state probability suggests that REER exhibits more stability in the long run, and it takes around 20 months to converge to equilibrium. In other words, this finding provides an explanation to purchasing power parity (PPP) in relative terms.

I. INTRODUCTION

In the post Bretton-Woods period, one of the important concerns of policymakers in choosing exchange rate regime is the influence of nominal exchange rate regime on real exchange rate volatility. Eventually, the prime objective to establish Euro area was to reduce real exchange rate volatility (Hau, 2002). Because real exchange rate volatility has some effects on the real sector of an economy including international trade and competitiveness. The currency crises in Europe, Asia, and Latin America in the 1990s also generated a renewed interest in the effects of exchange rate regime on real exchange rate volatility.

The prominent Mundell-Flemming-Dornbusch theoretical framework supports the idea of greater nominal and real volatility in flexible regimes under the assumption of short-run price rigidity and the PPP holds in the long run. Mussa (1996), Eichengreen (1994), Liang (1998) and others found that there is a positive correlation between real volatility and nominal exchange rate regime, at least in the short-run. Some of the theories and empirical studies, however, challenge this finding and argue that real exchange rate volatility is regime neutral (Helpman, 1981; Grilly and Kaminsky, 1991).

A recent study by Hausmann et al. (2006) examines the role of developmental stage on real exchange rate volatility. They find that long-term real effective exchange rate (REER) volatility is significantly higher in developing countries than in developed countries. They also argue that the differences in volatility are not due to the magnitude or frequency of shocks that developing countries face, but it is due to differences in persistence of volatility indicating that the way in which REER adjusts to shocks tend to imply more persistent swings in volatility, which they indicate a puzzle. However, it is not clear from the study how less developed economies adjust to long-term REER shocks.

The behavior of the real exchange rate across regimes and developmental stage is continued to be investigated. This paper makes similar attempt, however, it has some qualifications. *First*, it examines the role of nominal exchange rate regime and developmental stages on both short-term and long-term REER volatility. *Second*, it examines whether divergence from official regime has any implication on REER movements, particularly in less developed countries. *Third*, by applying the covariate-dependent Markov chain model it estimates steady-state probabilities and time to converge to equilibrium, which could provide some insights into the PPP debate.

For the analysis, this paper uses data of 18 countries including developing and developed countries for the period 1978-2004[1] (the list of countries is given in the Appendix I). For analyzing real exchange rate volatility, this paper considers volatility of the REER. The reason for using the REER instead of bilateral real exchange rates (RER)

[1] Not all the countries' REER is available for the whole period 1978-2004.

is to capture the effects of the level of development since the REER is a trade-weighted average of bilateral real exchange rates, which may better represent countries those are away from international financial centers and have diversified trade. As a methodology, the Markov chain model is used, which has long been used in studying volatility.

The moving average percentage change of the REER over a specific time-horizon (6-month for short-term volatility and 36-month for long-term volatility) is considered as a measure of volatility. The volatility series is then categorized into two states, stability and volatility, in terms of a threshold, which is the average of the volatility series. This makes it possible to apply the Markov chain model to REER movements for a panel of 18 countries' (10 developed and 8 developing) for the period 1978-2004[2]. A two-state Markov model, which is essentially an exponential regression model, is used to assess the effect of exchange rate regimes (both *de facto* and *de jure*) and developmental stage (developed and developing) on the movements of the REER. The details of the models are discussed in the Appendix II.

To summarize the main findings, this study finds that although short-term volatility is significantly higher in floating regimes, this regime helps adjust long-term real shocks. Developmental stages do not have any significant impact on real volatility; however, lower developmental stage helps REER adjustments to long-term real shocks. The results suggest that less developed economies usually adjust to long-term real shocks by changing their official exchange rate commitment without declaring it publicly. Based on the findings, it may be concluded that exchange rate regimes and developmental stages are not fully neutral to real volatility. Moreover, steady-state probability suggests that

[2] The theoretical underpinning of the procedure based on Markov chain rests on the assumption that exchange rate movements are governed by two states—stability and volatility, as well as in line with a strand of literature that demonstrates that there are important nonlinearities in exchange rate movements (e.g. see Coakley and Fuertes, 2000; Kilian and Taylor, 2002; Sarno and Taylor, 2002).

countries tend to maintain stability of the REER in the long run, and, on average, it takes around 20 months to converge to equilibrium.

The remainder of the paper is set out as follows. Section II reviews the literature on exchange rate volatility. Section III discusses the methodology and data used in this study and Section IV discusses the empirical findings. Finally, section V concludes the paper.

II. REVIEW OF LITERATURE

This section briefly reviews some of the theories and empirical studies that analyze the relationship of real exchange rate volatility with nominal exchange rate regimes and developmental stages.

Mussa (1986) analyzes the behavior of the bilateral real exchange rate of 15 industrialized countries and finds that bilateral RER were, on an average, 12 times higher under floating than under fixed exchange rate regimes. He compares the period of during and after the Bretton Woods and derived the conclusions from the summary statistics only. Grilly and Kaminsky (1991) criticize the empirical regularity between bilateral RER volatility and exchange regime (i.e. volatility is regime-dependent). They argue that RER volatility depends on the historical period rather than on exchange regime. Through their work they examined monthly observations of the RER between the US dollar and the British Pound during 1885-1986 and used Wald-Wolfovitz test. They found that the distribution of the monthly rate of change of the RER is the same under fixed and floating regimes only for the pre-World War II data, and that when post-World War-II data is included, different volatility behaviors across exchange regimes are found.

Liang (1998) criticizes the results of Grilly and Kaminsky (19991) obtained through the Wald-Wolfovitz test. Liang performs empirical analysis with annual data for the period 1880-1997, and monthly data for the period 1957-1997, and he used the GARCH model. His findings confirm that REER exhibits higher volatility in floating regimes than in fixed regimes. Kent and Naja (1998) analyze the relationship between the short-term volatility of the REER and the flexibility of the exchange rate regimes using non-parametric tests. Contrasting with the findings of many studies, they conclude that, for pooled results across countries, REER is only two-times volatile under floating regimes than under fixed regimes. However, results within countries show that there was no significant increase in REER volatility when moving to more flexible regimes.

Performing a dynamic panel data analysis under the Generalized Methods of Moments (GMM), Carrera and Vuletin (2003) analyze short-term REER volatility of the 93 countries for the period 1980-1999. They find that *de jure* fixed and intermediate regimes induce more volatility than *de jure* floating regimes.

Hausmann et al. (2006) studied REER volatility in developing and developed countries for a sample of 74 countries using annual data from 1980 to 2000. Based on ARCH estimates, they concluded that REER volatility is around 3 times higher in developing countries than developed countries. The difference in the long-run volatility is not due to magnitude or frequency of shocks but to the difference in persistence of the volatility that they indicate a puzzle.

Some earlier studies such as Huang (1981), Vander Kraats and Booth (1983) and Wadhwani (1987) followed Shiller’s (1981) work on stock price volatility to construct “variance bounds” tests of the monetary model of the exchange rate. Invariably, these studies found excessive volatility of exchange rates since the breakdown of the Bretton Woods. However, it is admittedly difficult to define what exactly is meant by the term "excessiveness”. A number of surveys indicate that short-term or high-frequency exchange rate movements are caused by 'speculative' or 'trend-following' elements rather than underlying macroeconomic fundamentals. Another point is that without a common benchmark, it seems difficult to define excessiveness of volatility (Bartolini and Bodnar, 1996).

Thus, there is no clear consensus about the connection between exchange rate regimes and the degree of real exchange rate volatility. Sercu and Uppal (2000) have recognized that differing results in different studies on the behavior of real exchange rate may be due to shortcomings of theoretical or empirical models, or shortcomings of data. Therefore, further studies are needed to be continued in this area in order to provide more insights into different aspects of real exchange rate volatility.

The efforts in this paper would be one of those trying to reach out to an empirical regularity by shedding light on different issues of real exchange rate.

III. METHODOLOGY AND DATA

III.1 Methodologies

Monthly percentage change of REER at *h*-horizon for 18 countries (see the list in the Appendix I) is considered to measure volatility as follows:

$$\Delta q_{t+h,i} = \left| \left(\frac{q_{t+h,i} - q_{t,i}}{q_{t,i}} \right) \right| * 100 = x_{ti} \tag{1}$$

where q_{ti} denotes the real effective exchange rate at time *t* of the country *i,* and *h* denotes time-horizon over which REER changes take place, which is 6-month for short-term volatility and 36-month for long-term volatility[3].

[3] Time-horizon is important in the discussion of volatility.

Based on Eq. (1), a categorical random variable y_{ti} is defined in terms of a threshold θ as follows:

$$
\mathrm{y}_{\mathrm{ti}} = \begin{cases} 1, \text{ if } x_{ti} \geq \theta, \text{i.e. } \mathrm{t}^{th} \text{ month is volatile for the i - th country} \\ 0, \; if \; x_{ti} < \theta, \text{ i.e. } \mathrm{t}^{\mathrm{th}} \text{ month is stable for the i - th country} \end{cases} \tag{2}
$$
$$
and \;\; \min \mathrm{x}_{\mathrm{ti}} < \theta < \max x_{ti}.
$$

For simplicity, θ is the threshold, which is considered as the long-term average percentage change of REER ($\bar{x}_i$) for the period 1978-2004. This technique is similar to the technique of calculating moving average standard deviation and taking deviation of it from its long-term trend, used by many authors, such as Kenen and Rodrik (1986), Kumar et al. (2003), Choudhry (2005).

Therefore, a two-state Markov chain model is applied to estimate the transition intensities between stability and volatility and to assess the factors that pushes REER to cross the threshold. The framework of the model can be schematically shown as follows:

$$
\begin{tikzcd}
\boxed{\text{Stability (0)}} \arrow[r, shift left, "\lambda_{01}\,(\beta_{01},\,\gamma_{01})"] & \boxed{\text{Volatility (1)}} \arrow[l, shift left, "\lambda_{10}\,(\beta_{10},\,\gamma_{10})"]
\end{tikzcd}
$$

The MSM model is defined as follows:

$$
\lambda_{ij}(t \mid z) = \lambda_{ij} e^{\phi_{ij}' z}; \text{ (i, j = 0, 1)} \tag{3}
$$

where ϕ denotes the vector of regression coefficients i.e. $\phi \in (\beta, \gamma)$, and λ represents the transition intensity between stability and volatility, which is defined as follows:

$$
\lambda_{ij} = \lim_{\Delta t \to 0} \frac{\Pr\{transition\ from\ "stability"\ to\ "volatility"\ in\,(t,\, t+\Delta t] \mid state\ i\ at\ time\ t\}}{\Delta t} \tag{4}
$$

This is an exponential regression based on Markov Chain assumption and it provides log-linear effects of coefficients on the REER movements between stability and volatility. Details of the model are discussed in the Appendix II.

The Markov assumption is that the probability of REER movements over h-month horizon being in one or another state next period depends only on the current state. While somewhat restrictive, it supposes that the typical currency will face the same likelihood that some shock will push it from its current state to the other, independent of past history. At any point in time, the distribution of states reflects these probabilities. To this end, to use a model that relies on Markov chain property may well predict about REER movements as a first approximation. And, higher order transition probability may predict volatility persistence, if any. If probabilities have changed over time, for example, due to increased capital integration among countries, the current transition probabilities may not be the same as the long run equilibrium (steady-state) probabilities. In that case, long run equilibrium transition probabilities may be of great interest, because it tells us what would be the long-run equilibrium probability of stability and volatility if the current transition probability remains unchanged. These properties give rise to the application of the Markov Chain model to REER volatility.

III.2 Data

III.2.1 Dependent variable

To allow for more systematic presentation, both short-term and long-term REER volatility are analyzed. The deviation of monthly percentage changes of REER over 6-month period from its long-term trend, represented by a categorical variable y_{ti} (as in Eq. 2, where 0 = stability and 1 = volatility) is the dependent variable for analyzing short-term volatility. Similarly, for long-term volatility, y_{ti} is calculated by considering monthly percentage changes over 15-month period. The decision about long-term period has taken on the basis of the results on the time to convergence, which is found to be 20 months, in general (see Table 4). The REER indices for the selected countries are taken from the International Financial Statistics (IFS) of the IMF.

III.2.2 Explanatory variables

This study considers nominal exchange rate regimes and developmental stages as explanatory variables. A broad categorization of exchange rate regimes is considered. For example, three broad categories, such as fixed, intermediate and floating regime consisting values"1", "2" and "3" respectively are considered. Another categorical variable is the developmental stage (Developing = 1 and Developed = 2)[4]. Thus, a positive sign associated with an explanatory variable means that a larger value raises the probability of developed economies and flexible regimes induce REER volatility.

Since countries often deviate from their official exchange rate regime without declaring it publicly, such non-linear policy might have implications for REER volatility. Therefore, a variable "divergence" (if both *de jure* and *de facto* regimes are the same, divergence gets 0; otherwise, 1) is estimated, and its impact on volatility across developmental stages is examined.

De jure regime classification is the one that the IMF officially publishes. This index is taken from IMF's Annual Report on Exchange Rate Arrangements and Exchange Restrictions. Several *de facto* regime classifications have been devised by some authors.

[4] Three-way classification of exchange rate regime is considered. Fixed regime consists of hard pegs such as currency union, currency board and dollarization; Intermediate regimes include all soft pegs and conventional fixed pegs and Floating regimes include managed floating and freely floating regimes. In our sample, the advanced countries are those who have high exposure to international capital markets, listed in the Morgan Stanley Capital International (MSCI) index: Australia, Canada, France, Ireland, Italy, Japan, Netherlands, New Zealand, United Kingdom and United States. Developing (or emerging) countries are: China, India, Malaysia, Mexico, Philippines, Thailand, Bulgaria and Saudi Arabia.

In this study, the de facto classification of Levy-Yeyati and Sturzenegger (2002) (hereinafter LYS) is considered to estimate the divergence. The regime classifications of the selected countries are documented in Table A1 and A2 in the Appendix I.

IV. EMPIRICAL RESULTS

In this section, persistence in volatility across regimes is examined by testing orders of the Markov chain. The effects of nominal exchange rate regime and developmental stage and their interaction are assessed under a covariate-dependent Markov model (see Marshal and Jones, 1995).

IV.1 Persistence in volatility

In this section, the chain dependence (Markov property) of the process, y_t, as well as the order of the Markov chain (MC) are tested in order to examine the persistence of volatility. Moreover, another motivation for testing the order of the Markov chain comes from the fact that, if the process y_t follows first order Markov chain, the multi-state Markov model can be applied as a first approximation to study the linkages between REER volatility, currency regimes and developmental stages. Anderson and Goodman (1957) proposed a likelihood ratio (LR) test statistic for this purpose to test the null hypothesis as follows.

H_0: $P_{ij} = P_j$ i.e. the process is of order zero.

H_1: $P_{ij} \neq P_j$, the process follows first order Markov chain.

The test statistic is:

$$\chi^2_{(m-1)} = \sum_{j=1}^{m} \sum_{k=1}^{m} \frac{\left(n_{jk} - n_{j.} n_{.k}\right)^2}{n_{j.} n_{.k} / n}, \tag{5}$$

where m denotes number of states and n_{jk}(t) denotes the frequency of transitions in state *j* at *t-1* to *k* at *t*. Rejection of the null hypothesis implies that the process (y_t) follows first order Markov chain.

Higher order of the Markov chain can be tested following Goodman (1955). He developed the LR test statistic to test the joint null hypothesis as follows:

H$_0$: $P_{ijkl} = P_{jkl}$, the process follows the second order Markov chain

H$_1$: $P_{ijkl} \neq P_{jkl}$, the process follows the third order Markov chain

That is, either rejection or acceptance has distinct meaning with this test procedure. The test statistic is:

$$-2\log L = \sum_{i,j,k,l}^{m} n_{ijkl}\left[\log \hat{P}_{ijkl} - \log \hat{P}_{jkl}\right] \sim \chi^2_{m^{r-1}(m-1)^2} \tag{6}$$

Where $\hat{P}$ denotes maximum likelihood estimate of transition probability, and r denotes the order of the Markov chain to be tested.

The results of the tests are reported in Table 1. Any regime-specific pattern in the order of the Markov chain is observed for long-term volatility; however, all the series follow the first order Markov chain. But volatility in floating regime is found to follow the second order MC, indicating that short-term volatility persists for longer time in floating regime than in intermediate and fixed regimes. Only the exception is the fixed exchange rate regime period of Italy—REER volatility in Italy during EU regime (1999 onward) follows the second order MC. This may be due to the fact that Italy faces unusually high inflationary episodes than neighboring countries in the EU that may lead to a high REER volatility persistence.

IV.2 Short-term REER volatility

Short-term volatility pattern across countries is shown in Figure 1. To assess the effect of currency regime and developmental stage on short-term REER volatility, the Markov model regression is applied. The results are reported in Table 2. The results show that the coefficient, γ_{01} is significant and positive, indicating that flexible regimes have significant effect on short-term REER volatility. Since the coefficient, β_{01} is not significant for both short-term and long-term volatility; therefore, developmental stages do not have any significant effect on swings in REER volatility either in the short-run or long run.

These findings are consistent with the viewpoint that at short horizons, floating exchange rates are associated with greater volatility of the real exchange rate as prices are sticky; at longer horizons, they may help offset inflation differentials, thus reducing real exchange rate volatility. However, developmental stages are neutral to real volatility, due to the fact that it is disconnected with macroeconomic fundamentals as argued by Deveruex (1997) and Deveruex and Engel (2002).

IV.3 Long-term REER volatility

The Markov model estimates for long-term volatility are reported in Tables 2 and 3. In Table 2, long-term volatility is estimated over 15-month time horizon, while estimates in Table 3 are obtained on long-term REER volatility estimated on 36-month time horizon. In both cases, the coefficients β_{01} (except for 36-month horizon) and β_{10} are significant and negative, and γ_{01} and γ_{10} are significant and positive, indicating that less developmental stage and flexible regimes have significant effect on long-term REER volatility and on their adjustments.

The results on steady-state probabilities in Table 4 suggest that real convergence to equilibrium is relatively quicker in floating regime as the time to convergence is lower in this regime than in fixed regimes. However, the level of development does not have such implications for the convergence. Since the time period is 20 months in which overall REER adjustments takes place, it may be concluded that PPP holds within 20 months[5]. The findings regarding REER convergence to its equilibrium seem reasonable because relatively faster convergence is emanating from smooth adjustment of shocks in floating regime, while the process of convergence is somewhat slow in intermediate and fixed regimes.

An important question is, how less developmental stage can make adjustments to REER shocks? In the following section, a modest attempt is made to provide an explanation to this question.

IV.3.1 Adjustments to long-term real shocks

The results in the previous section suggest that less developed economies can significantly adjust long-term real shocks. Despite the fact that less developed economies are less open and less integrated to global financial markets having less efficient financial system, these economies can possibly adjust long-term real shocks by manipulating their exchange rate policies unofficially. Deviating from the status quo, it provides a signal to market agents to change their expectations.

---

[5] Purchasing Power Parity (both absolute and relative) has implications for real exchange rate behavior. In a survey, Froot and Rogoff (1996) find that the consensus in the literature is that PPP holds in the long run, and that the half life of the deviations ranges between 3 and 4 years. However, recently Imbs et al. (2005) suggest that the average half-life is smaller than a year and criticizes that the previous consensus was based on aggregation bias. Again, Chen and Engel (2005) challenge the findings of Imbs et al. (2005).

To be sure about the relevance of such non-linear policy reactions to volatility, a variable "divergence" (0 = consistent, 1 = divergence) is created by comparing both *de jure* and *de facto* regime. Then the effect of the interaction variable (interaction of "divergence" and "dev") on long-term REER volatility is assessed. The results are reported in Table 5.

The estimates provide some interesting insights. The results show that the interaction term has negative and significant effect on long-term adjustments to real shocks. This indicates that less developed countries usually make significant readjustments to long-term real shocks mainly by deviating from their official exchange rate commitments. In other words, in a crisis period (e.g., high REER volatility period), exchange rate expectations and market spot rates may remain excessively sensitive to market developments and news. Under these situations, extrapolative expectations may be more likely to emerge and episodes of overshooting to occur. In the absence of an explicit commitment on the part of the authorities to defend a specific parity, intervention to smooth-out high frequency exchange rate movements may thus help to anchor agents' expectations about the path of the real and nominal exchange rates by removing much of the "noise" from the exchange rates. Therefore, by pursuing non-linear exchange rate policies, it is possible to achieve some real gains across less developmental stages.

To sum up, short term volatility is significantly higher in flexible regimes, which is consistent with many studies including Mussa (1986). Developmental stages do not have any implication for either short-term or long-term volatility, which seems contradictory with Hausmann et al. (2006). Both less developed economies and flexible regimes work in favor of adjusting long-term real shocks. The findings also suggest that divergence from *de jure* regime might have induced higher long-term real volatility in developed countries but not in developing countries. Therefore, less developed countries can bring stability in the REER movements through divergence from official exchange rate regime.

V. CONCLUSION

This study examines the linkages among REER volatility (both short-term and long-term), nominal exchange rate regimes and developmental stages for a panel of 18 countries for the post Bretton-Woods period. The findings suggest that flexible regimes induce higher short-term real volatility, but not long-term volatility. Developmental stages do not have any implication for short-term REER volatility; however, less developmental stage has implications for long-term REER volatility. Both flexible regimes and less developed economies have significant influence on the REER adjustments to long-term shocks.

Moreover, this study provides some insights into how less developed economies can significantly adjust to long-term real shocks. It finds that by deviating from official exchange rate policies, less developed countries usually make necessary REER adjustment to long-term shocks. The argument is that in the absence of an explicit commitment to defend a parity, intervention (by which divergence occurs) helps to anchor agents' expectations about the path of the real and nominal exchange rates by removing much of the noise from the exchange rate time series.

Deviations, i.e., the non-linear policy reaction might have varied implications for REER volatility across developmental stages. While divergence induces higher long-term REER volatility in developed economies, it reduces long-term volatility significantly in less developed economies. Therefore, both nominal exchange rate regimes and developmental stage do matter for REER volatility. For this reason, the implication for PPP is also different across regimes.

Table 1. Testing the order of the Markov chain (MC) for short-term volatility

Exchange Rate regime	Countries and time episodes	Testing for Markov property (First order MC) H_0: $P_{ij} = P_j$	Second order MC H_0: $P_{ijk} = P_{jk}$	Third order MC: H_0: $P_{ijkl} = P_{jkl}$
Fixed regime	Thailand (1990-95)	$\chi^2 = 19.38$ ($p < 0.01$)	--	--
	Mexico (1991-94)	$\chi^2 = 12.78$ ($p < 0.01$)	--	--
	France (1987-94)	$\chi^2 = 36.04$ ($p < 0.01$)	--	--
	Ireland (EU: 1999-)	$\chi^2 = 18.69$ ($p < 0.01$)	--	--
	Italy (EU:1999-)	$\chi^2 = 8.29$ ($p < 0.01$)	$\chi^2 = 1.65$ ($p = 0.79$)	--
Intermediate regime	Philippines (1978-04)	$\chi^2 = 110.4$ ($p < 0.01$)	--	--
	Netherlands (1987-96)	$\chi^2 = 36.80$ ($p < 0.01$)	--	--
	Malaysia (1980-95)	$\chi^2 = 17.41$ ($p < 0.01$)	--	--
	KSA (1980-04)	$\chi^2 = 48.42$ ($p < 0.01$)	--	--
	India (1979-92)	$\chi^2 = 56.84$ ($p < 0.01$)		--
Floating regime	Japan (1978-2004)	$\chi^2 = 108.2$ ($p < 0.01$)	$\chi^2 = 6.21$ ($p = 0.18$)	--
	UK(1978-2004)	$\chi^2 = 99.81$ ($p < 0.01$)	$\chi^2 = 1.36$ ($p = 0.85$)	--
	USA(1978-2004)	$\chi^2 = 92.66$ ($p < 0.01$)	$\chi^2 = 3.64$ ($p = 0.46$)	--
	Australia (1978-2004)	$\chi^2 = 91.87$ ($p < 0.01$)	$\chi^2 = 0.93$ ($p = 0.92$)	--
	New Zealand (1978-04)	$\chi^2 = 113.5$ ($p < 0.01$)	$\chi^2 = 1.06$ ($p = 0.90$)	--
	Canada (1978-2004)	$\chi^2 = 19.38$ ($p < 0.01$)	$\chi^2 = 1.58$ ($p = 0.81$)	--

Table 2. Estimated monthly swings in volatility and effects of exchange regimes and developmental stage on swings in volatility

Coefficient	Short-term volatility (6-month period)	Long-term volatility (15-month period)
A. Estimated transition intensities		
λ_{01}	0.21 (0.01)*	0.12 (0.06)*
λ_{10}	0.31 (0.01)*	0.20 (0.06)*
B. Effect of developmental stage		
β_{01}	0.06 (0.10)	-0.30 (0.12)*
β_{10}	-0.005 (0.10)	-0.26 (0.12)*
C. Effect of exchange rate regime		
γ_{01}	0.25 (0.06)*	0.57 (0.09)
γ_{10}	0.15 (0.06)**	0.56 (0.09)**
D. Estimated transition probabilities^{+}		
P_{00}	0.63	0.63
P_{01}	0.37	0.37
P_{10}	0.47	0.60
P_{11}	0.53	0.40
Log-likelihood	-2428.90	-3820.51
N	5008	5008

*Notes: (1) *and ** indicates 1% and 5% level of significance respectively; Standard errors are in parentheses.*

2. *Explanation of coefficients*: λ_{ij} should read as transition intensity from state i to j ; β_{ij} should read as the effect of developmental stage on transition from state i to j; γ_{ij} should read as the effect of exchange rate regime on transition from state I to j; and P_{ij} denotes the probability of transition from i to j.

Table 3: Long-term REER volatility and explicit causes

Coefficient	Long-term volatility
A. Estimated transition intensities	
λ_{01}	0.09 (0.006)*
λ_{10}	0.13 (0.008)*
B. Effect of developmental stage	
β_{01}	-0.04 (0.14)
β_{10}	-0.27 (0.13)**
C. Effect of exchange rate regime	
γ_{01}	0.31 (0.08)*
γ_{10}	0.27 (0.08)*
D. Effect of regime interaction (divergence × dev)	
α_{01}	-0.07 (0.08)
α_{10}	-0.18 (0.08)**
Log-likelihood	3798.11
N	4609

**, ** indicates significance at 1 percent and 5 percent level.*

Table 4. Estimated steady-state probabilities and convergence time (in months) for short-term volatility

	Fixed	Intermediate	Floating	Overall
Developed	35	25	12	20
Developing	35	25	12	
Probabilities	Stability: 0.62 Volatility: 0.38			

Table 5: Estimated steady-state probabilities of volatility in the cases of divergences

	Case I (De facto inter but de jure float)	Case II (De facto fixed but de jure intermediate)	Case III (Consistency)
Stability	0.34	0.33	0.69
Volatility	0.66	0.67	0.31

Case I: Developed vs. Developing

	Developed	Developing
Stability	0.44	0.55
Volatility	0.56	0.45

Case II: Developed vs. Developing

	Developed	Developing
Stability	0.56	0.76
Volatility	0.44	0.24

Figure 1: Monthly short-term REER volatility

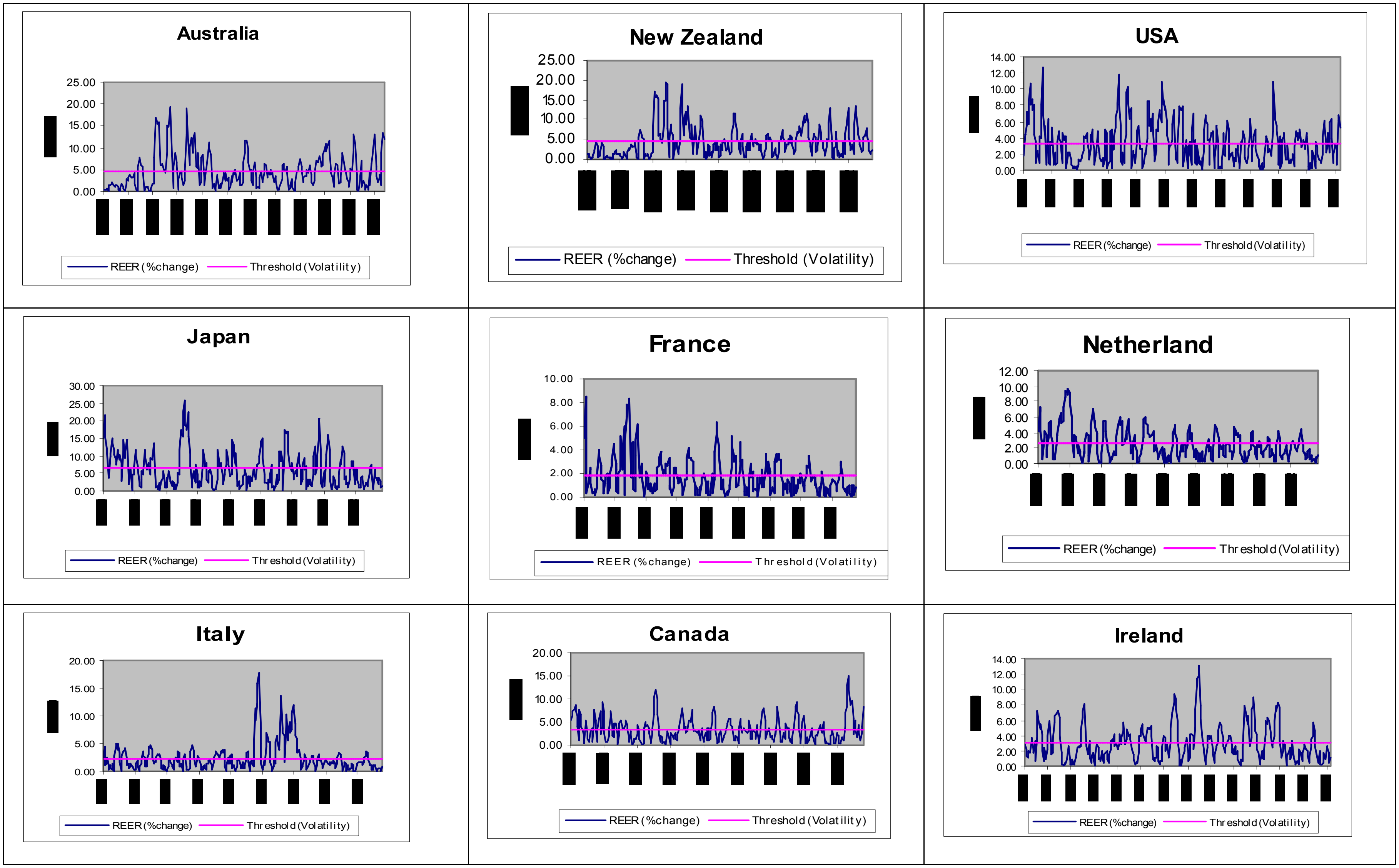
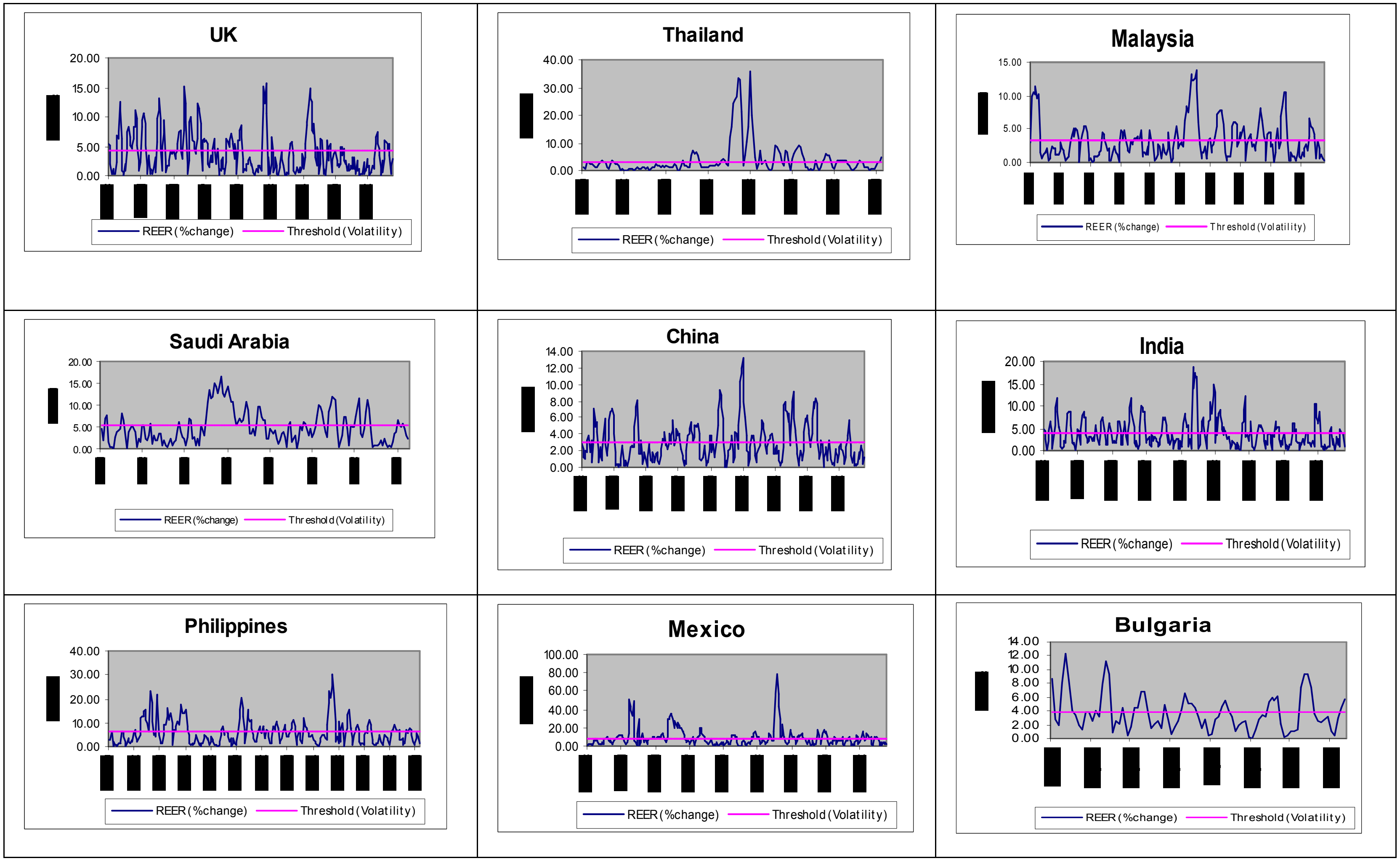


Figure 1 contd….



REFERENCES

Anderson, T. W. and L.A. Goodman (1957). “Statistical inference about Markov chains”. *The Annals of Mathematical Statistics*, Vol. 28, 89-110.

Bartolini, Leonardo and Gordon M. Bodnar (1996). “Are exchange rates excessively volatile? And what does "excessively volatile" mean, anyway?” Research Paper 9601, Federal Reserve Bank of New York.

Carrera and Vuletin (2003): “The effect of exchange rate regimes on real exchange rate volatility- A dynamic panel data approach”, paper presented at the 31st Brazilian Economics meeting, No. c67.

Chen, Shiu-Sheng and Charles Engel, 2005. "Does 'Aggregation Bias' Explain The Ppp Puzzle?" Pacific Economic Review, Blackwell Publishing, vol. 10(1), pages 49-72, 02.

Choudhry, Taufiq (2005). “Exchange rate volatility and the United States exports: evidence from Canada and Japan”, *The Journal of the Japanese and International Economies*, 19(2005), 51-71.

Coakley, J. and A. –M. Fuertes (2000). “Short run dynamics of real exchange rates”. *The Manchester School*, 68, 461-75.

Devereux, M. (1997). “Real exchange rates and macroeconomics: evidence and theory”, *Canadian Journal of Economics* 30, 773–808.

Devereux, M. and Engel, Ch. (2002). “Exchange rate pass-through, exchange rate volatility and exchange rate disconnect”, *NBER Working Paper 8858.*

Dickey, D. A. and W. A. Fuller (1981). “Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root”. *Econometrica*, Vol. 49, No. 4.

Eichengreen, Barry (1994). “International Monetary Arrangements for the 21st Century”, *Brookings Institution,* Washington DC.

Engel, C. and J.D. Hamilton (1991). “Long swings in the dollar: Are they in the data and do markets know it”? *American Economic Review* **80**, 689-713.

Frankel, J. and A. Rose (1995). *Empirical research on nominal exchange rates*, in G. Grossman and K. Rogoff (Eds.) Handbook of International Economics, 3, North Holland.

Frait, J. and L. Komárek (2001): “Real exchange rate tends in transitional countries”, *Warwick Economic Research Papers* No. 596.

Froot, Kenneth A. and Kenneth Rogoff (1996). "Perspectives on PPP and Long-Run Real Exchange Rates," NBER Working Papers 4952, National Bureau of Economic Research, Inc

Geweke, J., Porter-Hudak, S. (1983): "The estimation and application. of long-memory time series models." Journal of Time Series Analysis 4, 221 – 237

Goodman, L.A. (1955). “On the statistical analysis of Markov chains (abstract)”, *Annals of Mathematical Statistics*, Vol. 26, p.771.

Gotur, P. (1985). “Effects of exchange rate volatility on trade”. *IMF Staff Papers*, 32, 475-512.

Grilli, V. and G. Kaminsky (1991). “Nominal exchange rate regimes and the real exchange rate: Evidence from the United States and Britain, 1885-1986”, *Journal of Monetary Economics*, No 27, pp. 191-212.

Hau, Harald (2002). "Real Exchange Rate Volatility and Economic Openness: Theory and Evidence," *Journal of Money, Credit and Banking,* Blackwell Publishing, vol. 34(3), pages 611-30, August.

Hausmann, Panizza and Rigobon (2006) “The long-run volatility puzzle of the real exchange rate”, *Journal of International Money and Finance*, Vol. 25, No.1.

Helpman, E. (1981). “An exploration into the theory of exchange rate regimes”. *Journal of Political Economy*, 89.

Huang, Roger D. (1981). “The monetary approach to exchange rate in an efficient foreign exchange market: Tests based on volatility”. Journal of finance, Vol. 36, pp. 31-41.

Imbs, Jean, Haroon Mumtaz and Morten O. Ravn & Hélène Rey (2005). "Aggregation Bias" DOES Explain the PPP Puzzle," NBER Working Papers 11607, National Bureau of Economic Research, Inc

Kenen, P. and Rodrik, D. (1986). “Measuring and Analyzing the effects of short-term volatility in real exchange rates.”, *Review of Econ. Statistics,* 68, 311-315.

Kent, Christopher and Rafic Naja (1998) “Effective real exchange rates and irrelevant nominal exchange-rate regimes”, Research Discussion Paper 9811, Reserve Bank of Australia

Kilian, L. and M. P. Taylor (2002). “Why is it so difficult to beat the random walk forecast of exchange rates?” Discussion paper. Center for Economic Policy Research; forthcoming, *Journal of International Economics.*

Kumar, M.., Moorthy, U. and Perraudin, W. (2003). “Predicting emerging market currency crashes”. *Journal of Empirical Finance*, 10, 427-454.

Levy-Yeyati, Eduardo and Federico Sturzenegar (2002). Classifying exchange rate regimes: Deeds versus words. *Universidad Torcuato Di Tella.* Available via the internet at: www.utdt.edu/~fsturzen.

________________________ (2005) “Classifying exchange rate regimes Deeds vs. Words”, European Economic Review, Vol. 49, pp. 1603-35.

Liang, Hong (1998) “Real exchange rate volatility: Does nominal exchange rate regime matter”? IMF Working Paper, WP/98/147.

Marshalll, G. and R.H. Jones (1995). “Multi-state Markov models and diabetic retinopathy”. *Statistics in Medicine,* 14, 1995.

Mussa, Michael (1986). “Nominal exchange rate regimes and the behavior of real exchange rates: Evidence and implications”. *Carnegie-Rochester Conference Series on Public Policy,* Vol. 25, pp. 117-213.

Pippenger, M.K. and G. E. Goering (1993). “A Note on the Empirical Power of Unit Root Tests under Threshold Processes”, *Oxford Bulletin Of Economics And Statistics*, 1993

Samuel Karlin and Howard M. Taylor (1975). “A first course in stochastic processes”, 2nd ed.. Academic Press.

Sarno, L. and M. P. Taylor (2002). “Purchasing power parity and the real exchange rate”. *IMF Staff Papers,* 49, 65-105.

Sercu, P. and R. Uppal (2000). *Exchange rate volatility, Trade, and Capital flows under alternative exchange rate regimes*. Cambridge University Press.

Shiller, R. J. (1981). “Do stock prices move too much to be justified by subsequent changes in dividends”? *American Economic Review*, 71, 421-436.

Spilimbergo, A. and Vamvakidis, A. (2000). “Real effective exchange rate and the constant elasticity of substitution Assumption”. *IMF Working Paper, WP/00/128.*

Wadhani, Sushil B. (1987). “Are exchange rates excessively volatile”? Journal of International Economics, Vol. 22, pp. 339-48.

Vander Kraats, R. H. and L. D. Booth (1983). “Empirical tests of the monetary approach to exchange rate determination”. *Journal of International Money and Finance,* 2, 255-278.

APPENDIX I

List of countries and their exchange rate regimes

Table A1. The *de facto* and *de jure* exchange regime classification of the selected countries

Country	**De facto (LYS)**	**De jure**
Australia	1984-04: Float	1984-04: Float
Bulgaria	1997-04: Fix (Currency board)	1993-96: Float, 1997-2004: Fix
Canada	1974-2004: Intermediate/Float	1974-04: Float
China	1991-93: Managed Float	1970-90: Fix, 1991-2004: Inter
France	1974-1987: Inter/float 1988-1995: Fix [LYS] 1996-98: Inter [LYS] 1999-2004: Currency Union	1974-Float, 75:Inter, 76-78: Float, 79-98: Inter
India	1974-2004: Inter/Float	73-78: Fix, 79-92: Inter, 93-Float
Ireland	1974-2004: Fix [LYS] 1999-2004: Fix (Currency Union)	1973-78: Fix, 1979-98: Inter
Italy	1974-1998: Inter/Float [LYS]	1973-91: Inter, 1992-95: Float, 1996-98: Inter
Japan	1974-2004: Freely float	1974-81: Inter, 1982- Float
Malaysia	1974-98: Inter 1999-2004: Fix [LYS] 1990-97: Managed floating	1975-92: Fix, 1993-98: Inter, 1999- Fix
Mexico	1976-90: Inter/float 1991-94: Fix 1995-2000: Inter/float [LYS] 1994-2004: Float	1976-93: Inter, 1994- Float
Netherlands	1974-86: Inter 1987-96: Fix 1997-98: Inter 1999-2004: Fix [LYS] 1990-98: Fixed peg	1973-98: Inter
New Zealand	1980-87: Fix, 1988: Float, 1989: Float, 1990-04: Fix	1980-84: Fix, 1985-04: Float
Philippines	1974-2004: Inter/Float [LYS]	1973-: Float
Saudi Arabia	1980-2004: Fix [LYS]	
Thailand	1990-96: Fixed peg to basket	1973-81: Fix, 1982-83: Inter, 1984-96: Fix, 1997: Inter, 1998-Float
UK	1974-2004: Float	1973-90: Float, 1991: Inter, 1992-: Float
USA	1974-2004: Float	1973-:Float

Table A2: List of countries those deviated from their official currency regime

Officially floating but de facto intermediate	Officially intermediate but de facto fixed
Bulgaria (Jan. 1993-Dec. 1996) France (July 1978-Dec. 1978) India (January 1994-Dec. 1994) Italy (Jan. 1992-Dec. 1995) Mexico (Jan. 1995-Oct. 2004) Philippines (July 1980- Dec. 1993) Thailand (Jan. 1998-Dec. 1998)	Ireland (Jan. 1979- Nov. 1998) Mexico (Jan. 1990- Dec. 1993)

APPENDIX II

Two-state covariate-dependent Markov Model

This paper studies REER volatility using the Markov chain (MC) analysis. For more details, see Marshall and Jones (1995). Two states, stability and volatility, are considered within which countries' monthly REER often make transitions. It is assumed that there is no absorbing (i.e. state of death) state in the transition process. The transition intensity matrix is defined as,

$$\Gamma = \begin{pmatrix} -\lambda_{00} & \lambda_{01} \\ \lambda_{10} & -\lambda_{11} \end{pmatrix}. \quad \text{(A1)}$$

Elements of the matrix λ_{ij}'s are defined in Eq. (4). Assume that the transition intensities i.e. instantaneous rate of transition are independent of time and the intensities follow the property $\lambda_{ii} = -\sum_{i \neq j} \lambda_{ij}$; i, j = 0, 1, i.e. row sum is zero.

The relationship between the transition probability matrix **P**(t) and the transition intensity matrix Γ can be established with the Kolmogorov forward differential equation

$$\frac{\partial \mathbf{P(t)}}{\partial \mathbf{t}} = \mathbf{P(t)}\Gamma \,, \tag{A2}$$

where (i,j)th element of the matrix **P**(t), p_{ij} (i,j = 0, 1) represents the probability of transition from state i to j in a time interval t. Thus the transition probability matrix **P**(t) can be expressed as

$$\mathrm{P}(t) = \begin{pmatrix} p_{00} & p_{01} \\ p_{10} & p_{11} \end{pmatrix}. \tag{A3}$$

The solution of this system of differential equation can be expressed as

$$\mathbf{P}(\mathrm{t}) = \mathrm{A}\, diag \left\{ \mathrm{e}^{\rho_1 \mathrm{t}}, \mathrm{e}^{\rho_2 \mathrm{t}}, \mathrm{e}^{\rho_3 \mathrm{t}} \right\} \mathrm{A}^{-1}, \tag{A4}$$

where A is the square matrix containing in column i the eigenvector associated with the eigenvalue ρ_i of the transition matrix Γ. The solution to the characteristic equation $|\rho I - \Gamma(z)| = 0$ gives the eigenvalues of the intensity matrix Γ (z). The solution to the characteristic equation $|\rho I - \Gamma(z)| = 0$ gives the eigenvalues of the intensity matrix Γ (z). Since the intensity matrix is singular, one of the eigenvalue will be zero.

The Likelihood Function

Kalbfleisch and Lawless (1985) and later Kay (1986) describe a general method for evaluating the likelihood for a general multi-state Markov model in continuous time, applicable to any form of transition. The likelihood is calculated from the transition probability matrix P(t).

For a country j, the likelihood function is formulated as:

$$L(\theta) = \prod_j \left[P_{j00}(t\,|\,z)\right]^{s_{00}} \left[P_{j01}(t\,|\,z)\right]^{s_{01}} \left[P_{j10}(t\,|\,z)\right]^{s_{10}} \left[P_{j11}(t\,|\,z)\right]^{s_{11}} \tag{A5}$$

where $\theta = (\lambda, \beta, \gamma)$. The variable s_{ij} takes value 1 if transition occurs and 0 otherwise. For example, if at time t, a country is in state 1 (stable state), at time t+1, the country can be in either of the states 0, 1 (volatile). Therefore, $s_{00+} s_{11} = 1$, and so on. The log-likelihood function can be calculated by taking log of the likelihood function.

The maximum likelihood estimates of $\theta = (\lambda, \beta, \gamma)$ can be obtained by maximizing the log likelihood, and applying any of the iterative procedures such as the quasi-Newton algorithm or Nelder-Mead simplex-based algorithm. MSM estimates are obtained by using the 'msm' package of **R** software and package.