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Non-Linear Properties of Currency Crises in Emerging Markets

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Abstract

The major objective of this paper is to test for the presence of non-linearities in the data generation process of exchange rate fluctuations in emerging markets. Estimating an econometric model with a unique set of macroeconomic and financial monthly data for a panel of 32 emerging market economies over the period 1985-2002, significant non-linearities are detected. These mainly stem from fluctuations in foreign reserves, global price pressures, interest rates, and export growth. Moreover, we find evidence of an error correction mechanism with respect to exchange rate deviations from trend, which ceases to be effective when a currency crisis is looming.

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1. Introduction

The currency crises in Asia, Russia, and Brazil were largely unforeseen, despite the large amount of theoretical and empirical literature on the determinants of currency crashes. The severe destabilizing impact these crises have exerted on all major sectors of the economies, including the banking industry, financial markets, as well as private consumption and investment, and hence on economic growth and living standards, are well known. The apparent lack of means to detect signals that may have helped to prevent these crises, and indeed their accumulation, is worrying if not alarming and challenges the current research to deliver more effective tools. This is even more relevant in light of the unbalancing influence currency crashes in developing countries can have on the world economy through repercussion effects via international trade and investment flows. Gaining a better understanding of what factors may serve as early warning signals of looming currency imbalances and by that reducing the exposure to the risk of future currency crashes therefore remains of immediate interest and importance to policy makers, financial market participants, and researchers. In this paper we wish to explore two extensions to the existing work: the impact of non-linearities and the impact of cumulative small changes rather than one-off large ones.

A popular approach to assessing the determinants of currency crashes has been to use binary choice techniques such as Logit or Probit models to explain crisis events in a variety of country panels. Recent examples include Kumar *et al* (2003), Frankel and Rose (1996) as well as Eichengreen *et al* (1995). While these types of models have the advantage of assessing the probability of a crash, they rely on certain pre-defined criteria of what is seen as a 'crisis' event. However, the vulnerability with respect to exchange rate devaluations is likely to differ between economies, so that one criterion may not fit all. The nature of these models implies that they explain only very large movements in the dependent variable. Hence factors causing exchange rate variations which do not qualify as a 'crisis' but which are nonetheless large enough to have a destabilizing impact, possibly preceding an eventual crash, may be overlooked, we argue. A large depreciation defined as a crisis also may result from a sequence of small devaluations of the exchange rate, rather than just few or one-off large ones, in which case binary choice models may not identify signals of the crisis. The first extension to the current literature that we therefore wish to explore is to conduct an analysis that allows an assessment on the determinants of large as well as small movements in exchange rates in emerging markets.

Secondly, we test for the presence of non-linearities in exchange rate movements where we exploit the fact that many of these economies have only recently been developing more advanced financial markets and exchange rates, for example, so they experience rapid growth, having started from a position far away from equilibrium. The investigation of non-linearities has been paid increasing attention by the general macroeconomic literature (e.g. Pesaran and Potter, 1993), and Funke *et al* (1997) provide strong evidence for the presence of non-linear properties of the zloty-dollar exchange rate over the period 1955-1990. However, potential non-linearities have so far been neglected in the existing panel data work on the determinants of currency crises. Extreme observations tend to be accommodated by the fit of a model that is linear in the regressors, so the existence of these observations may remain undetected. Including dummies for outlying observations does not seem appropriate when the analysis is focussed on short-run developments and when one objective is to assess the impact of shocks in the explanatory variables. We therefore include non-linear terms in our model so as to explicitly test for the presence of non-linearities.

We estimate an econometric model of exchange rate fluctuations, using a unique data set of macroeconomic and financial monthly data for a panel of 32 emerging market economies over the period 1985-2002. The theoretical literature suggests that an effective system to detect looming currency crises include a broad range of potential indicators. We incorporate variables from the categories of indicators identified by the theoretical and empirical currency crises literature in our analysis and also consider variables such as portfolio investment whose impact has rarely been tested so far. Regarding the major objective of our analysis, we detect the presence of significant non-linearities in the data generation process underlying real exchange rate changes in emerging markets. These mainly stem from fluctuations in foreign exchange reserves as a ratio to imports, export growth as well as changes in global price pressures and interest rates. High export correlation with a country experiencing large devaluations of its currency seems to intensify the risk of crisis contagion. Moreover, we find evidence of an error correction mechanism with respect to exchange rate deviations from trend, which ceases to be effective when a crisis is looming. Evidence suggestive of asymmetries is also found with respect to the effect of interest rate increases which tend to be destabilizing in turbulent times.

The paper is structured as follows. Section 2 briefly addresses the existing literature and some methodological considerations. Section 3 outlines our model of real exchange rate fluctuations as well as the major steps undertaken to construct a clean and consistent data set. The regression results and various sensitivity tests are presented in section 4. Section 5 concludes.

2. The existing literature and methodological considerations

The theoretical literature suggests that an effective system to detect looming currency crises include a broad range of potential indicators. The traditional approach, going back to Krugman's (1979) model of balance of payments crises, emphasises a gradual but persistent fall in foreign exchange reserves as the major indicator of a crisis. Extensions of the seminal model ascribe predictive power also to factors including movements in the real exchange rate, fiscal variables, the current account and trade balance as well as domestic interest rates.[1] More recent models find that other macroeconomic variables such as output and public debt may be important determinants of currency crises if they enter the authorities' objective function (e.g. Ozkan and Sutherland, 1995, and Cole and Kehoe, 1996, respectively). Regional contagion effects or transmission of crises through high trade correlation, enhancing an economy's vulnerability to external shocks, have also been a growing area of interest in recent years (Glick and Rose, 1999, as well as Eichengreen *et al*, 1995 and 1996, for instance). The available empirical evidence supports the importance of many of these potential indicators.[2] International reserves, the real exchange rate, and domestic inflation are amongst the variables that appear to matter most. Exports and real output growth are also often found to be important determinants of crises, while foreign debt as well as the current account balance generally fail to be significant. Surprisingly perhaps, the empirical evidence with respect to the government budget deficit is not clear-cut either (see Kumar *et al*, 2003 as well as Frankel and Rose, 1996 for two recent examples).

[1] Flood and Marion (1997, 1999) as well as Garber and Svensson (1994), for instance, provide surveys of both the traditional and the more recent theoretical literature.

[2] See Kaminsky *et al* (1998) for a recent survey.

The impact of monetary policy on exchange rates during the Asian financial crisis has been given particular attention, being the subject of a major policy debate between the IMF and the World Bank. The position of the IMF has been that stabilization of Asian exchange rates relied significantly upon substantial monetary tightening. By contrast, the World Bank has argued that steep rises in interest rates caused further destabilization of the currencies by increasing the probability of bankruptcy of highly leveraged borrowers (Stiglitz, 1999, Gertler *et al*, 2000). Empirical evidence from panel data analyses tends to support the latter view, whilst the evidence resulting from VAR models is mixed.[3] Estimating a bivariate Vector Error Correction Model, Caporale *et al* (2005) find that an increase in nominal interest rates leads to a nominal appreciation of the domestic currency in tranquil periods, whereas excessive tightening during the Asian crisis contributed to the eventual collapse of the exchange rates.

A popular approach to assessing the determinants of currency crashes has been to use binary choice techniques such as Logit or Probit models to explain crisis events in a variety of country panels. Recent examples include Kumar *et al* (2003), Frankel and Rose (1996) as well as Eichengreen *et al* (1995). While these types of models have the advantage of assessing the probability of a crash, they rely on certain pre-defined criteria of what is seen as a 'crisis' event. The nature of these models also implies that they explain only very large movements in the dependent variable. Hence factors causing exchange rate variations which do not qualify as a 'crisis' but which are nonetheless large enough to have a destabilizing impact, possibly preceding an eventual crash, may be overlooked. A large depreciation defined as a crisis also may result from a sequence of small devaluations of the exchange rate, rather than just few or one-off large ones, in which case binary choice models may not identify relevant signals of the crisis. An empirical model in general would attempt to explain all movements in the variable of interest, however, and one objective of this paper therefore is to use normal regression analysis to investigate the determinants of exchange rate fluctuations in our sample of 32 developing countries.

The analysis of a sample of emerging market economies provides an opportunity to test for the presence of non-linearities in exchange rate movements. Many of these economies have only recently been developing more advanced financial markets and exchange rates,

[3] For a concise review of the existing literature on the relationship between exchange rates and monetary policy, see Caporale *et al* (2005).

for example, so they experience rapid growth, having started from a position far away from equilibrium. Extreme observations tend to be accommodated by the fit of a model that is linear in the regressors, so existence of these observations may remain undetected. Our model therefore includes cubic terms of the explanatory variables in addition to the linear terms in order to allow us to explicitly test for the presence of non-linearities. We consider cubic rather than quadratic terms so as to preserve the sign of the underlying data.

Most empirical analyses focus on the period(s) defined as a crisis and do not consider regime switches and potential asymmetries in the effects of the crisis indicators. Knowing which indicators may have a different impact in a period of rapid devaluations compared to tranquil times could however provide valuable insights for accommodating policy action. The conclusions drawn by Caporale *et al* (2005), for instance, suggest monetary tightening during the Asian financial crisis should have been more cautious because of the risk of its aggravating rather than halting the fall of the currencies. In this study, policy shifts are taken account of by intervention dummies equal to one in periods of sharp increases in interest rates during the crisis. We propose an alternative way in our panel analysis. By differentiating between linear and non-linear terms over the long investigation period, the coefficient of the non-linear transformation provides information on an indicator’s impact in turbulent times, since magnitudes of a non-linear order do not occur in tranquil periods. The existence of asymmetries is examined for all indicators of the model.

3. The econometric model and data

In the general model we started our analysis from, we include variables from each of the categories outlined above. The econometric model can be expressed as

$$\Delta \ln\left(RE_{it}\right) = \alpha_i + X_i^{'}\beta + X_i^{c'}\gamma + DUMMY_{it}^{'}\delta + \lambda_1 TREND_t + \lambda_2 CTREND_t + \varepsilon_{it} \qquad (1)$$

where the vector of regressors X_i for each country i, which enter the regression in linear and non-linear[4] form, and the vector of dummy variables are

[4] The elements in X_i^c are the cubed elements of X_i.

$$
\begin{aligned}
X_i = \; & [\Delta \ln\left(RE_{i,t-1}\right),\ \ln\left(REDT_{i,t-1}\right),\ \ln\left(GDP_{it}\right),\ \ln\left(GDP_{i,t-1}\right),\ \ln\left(GDP_{i,t-2}\right), \\
& \ln\left(EXP_{it}\right),\ \ln\left(EXP_{i,t-1}\right),\ \ln\left(EXP_{i,t-2}\right), FDI_{it}, FDI_{i,t-1}, FDI_{i,t-2}, \\
& FX_{it}, FX_{i,t-1}, FX_{i,t-2}, FXIMP_{it}, FXIMP_{i,t-1}, FXIMP_{i,t-2}, \\
& DEBTR_{it}, DEBTR_{i,t-1}, DEBTR_{i,t-2}, BUDR_{it}, BUDR_{i,t-1}, BUDR_{i,t-2}, \\
& \ln\left(M3_t\right),\ \ln\left(M3_{t-1}\right),\ \ln\left(M3_{t-2}\right),\ \ln\left(COM_t\right),\ \ln\left(COM_{t-1}\right), \\
& \ln\left(COM_{t-2}\right), IR_t, IR_{t-1}, IR_{t-2}]'
\end{aligned}
$$

and

$$DUMMY_{it} = [HINFA_{it}, HINFB_{it}, REG_{it}, EX_{it}]'.$$

The variables included are measures of the real effective exchange rate (RE_{it}) of country *i* at time *t* and its deviation from trend ($REDT_{i,t-1}$), real GDP and export (EXP) growth, changes in real foreign exchange reserves (FX) as well as their share in imports (FXIMP), the ratio of foreign public to foreign total debt (DEBTR), the government budget deficit as per cent of GDP (BUDR), and real domestic interest rates (IR). In order to capture an economy's vulnerability to external shocks through international financial and capital flows, we also consider foreign direct investment (FDI). Following Kumar *et al* (2003), we include a global liquidity indicator, which is approximated by a measure of real broad money for the OECD countries, excluding high-inflation countries (M3). Global price pressures are controlled for by a non-fuel commodity price index (COM). The impact of inflation is implicitly accounted for by including real variables throughout. This differs from other studies such as Kumar *et al* (2003), for instance, which include nominal variables or a combination of real and nominal ones in order to explain devaluations of the real exchange rate. In addition, inflation directly enters our regression via two dummy variables: First, we include Kumar *et al*'s (2003) criterion of inflation acceleration of more than 100% (HINFA)[5]. However, since this may include low-inflation regimes as well as high-inflation ones, we also incorporate a variable that captures annual inflation rates above 100% (HINFB). Finally, the model includes two measures of possible contagion

[5] In one case, the rate of acceleration was exactly 100 per cent, which was set to one as well.

effects, through geographic proximity to (REG) and through high export correlation with (EX) a country which has experienced a large exchange rate depreciation of 5% or above within the last three months.[6] TREND, CTREND are a linear and a non-linear trend, respectively.

α_i denotes fixed effects so as to control for unobserved heterogeneity between countries. This important tool is not available in binary choice models on currency crises because the number of crashes which can readily be defined in the samples for each individual country usually is too small, as recognized in Kumar *et al* (2993), for example. Similarly, the nature of these models precludes the application of diagnostic tests for key issues such as serial correlation. Indeed, the latter is typically inherent in the specifications and, undetected, has led to downward biased standard errors and consequently over-optimistic conclusions on the statistical significance of determinants in many studies (Berg and Coke, 2004). The lagged dependent variable and the deviation from trend of the level of the dependent variable are treated endogenously, using their second lags as well as the third lag of the exchange rate as instruments, in order to avoid any potential bias according to Nickell (1981).

For all regressors X_i other than the lagged dependent variable and its deviation from trend we include the current term as well as the first and second lag in our general model. The existing literature in general looks either at the impact of current variables or at the impact of variables lagged once. However, a crisis may be the result of cumulative changes over several periods, which is one argument for considering different time periods simultaneously. This also allows us to assess the importance of dynamic terms. For many of the variables, the coefficients of two consecutive terms were insignificant but added up to zero. We consequently included only the differenced term in these cases, and significance of its coefficient indicated a purely transitory effect of the respective variable which of course may be very important for a crisis. We also conducted respective linear restrictions tests. The model was further tested down to the more parsimonious specification used for inference in the usual way.

[6] Our export growth correlation dummy is based on annual growth, which is the export variable included in regression, and hence differs from that in Kumar *et al* (2003), who consider monthly growth correlations over the past 48 months.

We use a unique data set of macroeconomic and financial monthly data for a panel of 32 developing countries over a period of 17 years, 1985-2002.[7] The original data set has 6912 observations, the number of which was reduced to 5323 in regression because of missing values. We use an unbalanced panel as this allowed a much larger sample to be exploited than using a balanced panel could do. The data are taken from a variety of international and national sources. The breakdown of the series and the individual sources are detailed in the appendix. Many of the growth and trend deviation transformations of the variables included in regression are in line with those used in Kumar *et al* (2003).[8] However, following the usual practice in the macroeconomic literature we calculated the trend of a series by applying a Hodrick-Prescott filter (Hodrick and Prescott, 1980, 1997). The deviation from trend is stationary by definition, so by including REDT we are capturing the long-run bit of the model but we are mostly interested in the dynamics which is what we are concentrating on. We were very careful to construct a clean and consistent data set. Missing monthly values were interpolated only when there were points of genuine data for the year in question so as to ensure interpolation of missing observations would not distort results.[9] Many interpolated values were obtained by using information on the same series from a different source or on a related series as available in order to make use of as much genuine data as possible. In the absence of any other information, interpolation was performed by natural cubic splines.

4. Results

The major results of our analysis are summarized in table 1. The ratio of foreign exchange reserves to imports is treated as endogenous, as suggested by a Hausman (1978) test. The endogeneity of the ratio seems to come through the revaluation effect on imports following a change in the exchange rate rather than through foreign exchange reserves. Hausman tests for foreign reserves and exports suggested these be treated as exogenous. An economic explanation may be that a depreciation of the exchange rate will result in an immediate increase in current import values since imports are usually held in foreign

[7] Data for Kuwait were excluded for the period surrounding the gulf war, 1990-1992. A large part of the data for this period was missing, and the available data are likely to be distorted.

[8] See table 1 for details.

[9] Any other missing observations were left missing. This caused a particularly large number of missing values for portfolio investment (PORT), which would have excluded some countries almost entirely from the data set and which is why PORT was not included in our main analysis. See section 3 for details.

currency but converted to domestic currency for accounting purposes, while from a domestic point of view the a priori value of other variables will remain unchanged.

When including monthly time dummies, the regression failed to converge due to the large additional number of explanatory variables. Regression [1] therefore does not include any time dummies but the two time trends which are clearly significant. Instead of monthly time dummies, we included a full set of year dummies in regression [2]. Except for two, the time dummies are individually insignificant at conventional significance levels. Inspection of the results further reveals that the two regressions' standard errors are essentially the same, and the coefficients of the explanatory variables in [2] do not change much in general compared to [1], although the coefficient on commodity prices is reduced somewhat. This suggests that the trend that is apparent in the profile of the year dummies is almost as well approximated by the time trend variables included in regression [1]. Jointly the time dummies in [2] are highly significant according to a Wald test, whilst the linear and non-linear time trends are insignificant both individually and jointly. Thus the year dummies appear to provide some significant information over and above that captured by the trends and were therefore included in the remaining regressions.

While foreign direct investment does not appear to have any important impact on exchange rate changes in [1],[10] regression [2] shows that even if we accepted a type I error at the lower end of the 10% spectrum as indicating significance, any impact from foreign direct investment were not robust to the inclusion of time dummies in the model. In [3] we therefore eliminate FDI, as well as the insignificant trends, from the regression.[11] As table 1 shows, the results for the other variables generally remain robust to these changes. However, most of the time dummies become significant, which provides further evidence that the coefficient on FDI was mainly picking up common time effects. As a further test of sensitivity of the regression results, we exclude the insignificant trends and the inflation and regional contagion dummies from the instrument list of model [4]. Again, the regression results prove robust.

[10] The impact of FDI on currency crises has not been tested for very frequently so far, and the available evidence is mixed. Frankel and Rose (1996), for example, find a significant negative effect of FDI measured as a ratio to debt, whereas the results in Kumar *et al* (2003) suggest insignificance.

[11] Without FDI, CFDI became highly insignificant, and jointly the two variables were also insignificant.

In line with much of the literature which uses binary choice techniques to explain currency crises, we find no evidence of a significant impact from public foreign debt relative to total debt and from the government's budget position. Our results, however, suggest not only that foreign debt and the public deficit are not significantly related to currency crashes but also that they do not have any important effect on exchange rates in tranquil times. Similarly to the results in Kumar *et al* (2003), the global liquidity indicator equally fails to be significant, as do linear global price pressures. However, the coefficient on the first lag of the non-linear commodity price variable is relatively large and positively significant. This suggests that while global price increases do not usually have an important effect on exchange rates in emerging economies, they do ceteris paribus trigger large depreciations in exchange rates when they jump substantially.

Similarly to much of the currency crisis literature, we find a significant and negative impact of real GDP growth, expressed as the deviation from trend, on changes in the real effective exchange rate. A slowdown in annual GDP growth or a contraction which exceeds that from the previous period, for example, precede exchange rate depreciations.

Due to the importance attached to foreign exchange reserves in the theoretical as well as empirical literature, they were included in our regression twice, expressed as annual growth and as a ratio to imports. The latter have a very significant linear as well as non-linear impact on exchange rates, both with the expected negative sign. There seems to be only a marginal negative, non-linear effect from annual growth in reserves, which fails to be significant when applying a 5% critical value, however (p-value of 0.066).

The coefficient on the lagged dependent variable is positive, suggesting that depreciations in one period carry forward to the next. However, the coefficient is not significant at conventional levels. By contrast, the negative sign of the exchange rate deviation from trend in the previous period indicates the presence of an 'error correction mechanism'. In those cases in which the effects from the two exchange rate terms will go into opposite directions, the corrective mechanism will prevail as the respective coefficient is highly significant. It is notable that this mechanism seems to be existent only in the linear case. In situations of very large devaluations with a potential imminent crisis, i.e. in the non-linear case, the coefficient of the trend deviation variable is very insignificant, as is that of the lagged dependent variable.

As we would expect, a rise in domestic interest rates in general is, other things equal, associated with an increase in the relative value of the domestic currency. The non-linear interest rate term enters the regression with a significantly positive sign, however. This seems to support those theoretical models which predict an increase in domestic interest rates at times of a looming crisis. The monetary authorities raise interest rates dramatically in an attempt to prevent the value of the currency from falling even further. This seems to have some of the intended impact by slowing the aggravating, 'snowball' depreciation effects, as reflected in the insignificance of the non-linear lagged exchange rate terms, both of which became insignificant when the dynamic interest rate terms were introduced into the regression. However, at a time when we observe very large interest rate changes, any crisis appears to be too advanced for further devaluations and an eventual crash to be prevented by monetary policy, so that the coefficient is still positive. The coefficient may also be picking up some reverse causation effect, however interest rates were clearly exogenous according to a Hausman test.[12]

Our result on the asymmetric effect of tighter monetary policy on exchange rates is in line with that found by Caporale *et al* (2005). It appears to be an important phenomenon suggesting monetary authorities respond more cautiously to observed large devaluations of the domestic currency. The similarity of the results is even more noteworthy in the light of the fact that the country sample, the empirical model and estimation method as well as the measurement of tranquil versus turbulent times differ between the two studies.

The results further indicate that the risk of crises contagion increases with the degree of exposure to external markets, as reflected by the positive and significant coefficient on our trade contagion dummy. Large declines in the growth rate of exports themselves seem to exert upward pressure on the exchange rate, whereas there is no evidence of a linear association between slowing export growth and a currency devaluation.

[12] The potential endogeneity of interest rates has not been considered in many earlier empirical studies. A recent example to the contrary is the study by Caporale *et al* (2005) which takes into account the simultaneous feedback between interest and exchange rates by estimating a bivariate VECM and identifying the system by exploiting the heteroscedastic properties of the two time series.

Table 1. Pooled panel data results for exchange rate fluctuations

Dependent Variable: RE_{it}^{a}

	[1]	[2]	[3]	[4]
$RE_{i,t-1}^{a}$	0.2091650 (1.9)	0.1977230 (1.9)	0.2060290 (1.9)	0.1870680 (1.8)
$REDT_{i,t-1}$	-0.1736800 (5.5)	-0.1845240 (5.2)	-0.1821720 (5.2)	-0.1866300 (5.0)
$GDP_{it}^{b,c}$	-1.9343500 (2.5)	-1.9124200 (2.3)	-1.9046800 (2.3)	-1.9360000 (2.3)
$FDI_{i,t-1}^{b}$	-0.0001026 (1.7)	-0.0000995 (1.6)		
$FXIMP_{it}^{a}$	-0.0040149 (2.9)	-0.0042908 (3.0)	-0.0043358 (2.9)	-0.0041079 (2.9)
IR_{it}^{a}	-0.0000009 (44.0)	-0.0000009 (47.5)	-0.0000009 (45.3)	-0.0000009 (45.2)
EX_{it}	0.0059787 (2.0)	0.0060217 (2.0)	0.0060998 (2.0)	0.0061447 (2.0)
TREND	0.0001124 (3.3)	-0.0004495 (1.3)		
CTREND	-1.7e-009 (2.7)	4.5e-009 (0.8)		
$CRE_{i,t-1}^{a}$	0.1283100 (0.5)	0.1455240 (0.6)	0.1278370 (0.5)	0.1489900 (0.6)
$CREDT_{i,t-1}$	-0.0251300 (0.1)	0.0137002 (0.0)	-0.0103215 (0.0)	0.0137403 (0.0)
$CEXP_{i,t-1}^{a,b}$	-0.0017780 (2.6)	-0.0017848 (2.5)	-0.0017759 (2.5)	-0.0017895 (2.5)
$CFDI_{i,t-1}^{b}$	1.7e-010 (1.9)	1.6e-010 (1.8)		
$CFX_{i,t-1}^{a,d}$	-0.0000085 (1.9)	-0.0000091 (1.9)	-0.0000088 (1.9)	-0.0000089 (1.8)
$CFXIMP_{i,t-1}^{a}$	-0.0000022 (2.6)	-0.0000024 (2.5)	-0.0000024 (2.4)	-0.0000023 (2.6)
$CCOM_{i,t-1}^{d}$	0.6299620 (3.6)	0.5788630 (2.2)	0.6172310 (2.3)	0.6307410 (2.3)
$CIR_{i,t}^{a}$	1.9e-018 (25.9)	1.9e-018 (27.3)	1.9e-018 (25.8)	1.9e-018 (27.6)
No. of obs.	5323	5323	5323	5323
Std. Error	0.047	0.047	0.047	0.047
AR(1)	-0.649	-0.643	-0.637	-0.581
AR(2)	-1.288	-1.209	-1.194	-1.024

Note: T-statistics in parentheses are based on robust standard errors. Fixed effects are included in all regressions. RE, REDT, GDP, EXP and COM are in natural logarithms. [a] First differenced. [b] Deviation from trend of twelve-months per cent change. [c] Differenced twice. [d] Twelve-months per cent change (annual growth).

Regressions [2]-[4] include a full set of year dummies (1987-2001). In [2], they are significant at the 5% level for the years 1989 and 1994 (t-statistic of 1.9 for 1988 and 1990). The time dummies are jointly significant at the 1% level. In [3] as well as [4], the year dummies are significant at the 1% (5%) level for 1989, 1990, 1992-1994, 1996, 1997, 2000, 2001 (1991, 1999). Regression [4] excludes the insignificant trends as well as the contagion and inflation dummy variables from the list of instruments.

AR(1) and AR(2) are tests of first- and second-order serial correlation. They are distributed $N(0,1)$ under the Null.

The inflation dummies included in the regressions were not significant. We experimented with different cut-off points for our high-inflation regime dummy and found that with a threshold inflation rate of 1000% to be highly significant with the expected positive sign, as shown in table 2, regression [5] (HINFB1000). This suggests that only very high inflation is likely to have an impact on exchange rates that is not captured by other variables and, consequently, that inflation matters only for a subset of countries. At the threshold level of 1000, the dummy is equal to one for only five of the 32 countries in the sample, and only for a few periods. Hence the results also indicate that exchange rate changes in some countries follow a different process than in others. The results with respect to the other explanatory variables are very similar to those in [4]. We also experimented with including exports, foreign exchange reserves, and FDI as a ratio to GDP, but this did not significantly alter the results.

Portfolio investment (PORT) was not included in our main model as there is a particularly large number of missing values for this series, which would have excluded some countries almost entirely from the data set and reduced the number of observations by 1131. In order to still get some idea about the potential impact of portfolio investment on exchange rates, we estimated additional regressions where we added this variable to regression [4]. As before, we first included the current value as well as the first and second lag, and regression [6] in table 2 presents the model with the resulting nested transformations of PORT.[13] A contraction of portfolio investment tend to devalue the effective exchange rate, and there is evidence of the presence of non-linearities. The qualitative results with respect to the other coefficients remain similar to those in [4], with the exception of the coefficient on cubed exports which becomes insignificant. Looking at the quantitative results, we find that the coefficient on the trade contagion dummy increases significantly. This is similar for the linear lagged dependent variable as well as for non-linear foreign reserves, while the coefficient on commodity prices falls somewhat. However, considering the number of changes that are imposed on [6] relative to [4], i.e. the size as well as the composition of the sample and the addition of another (significant) explanatory variable, the overall results in general appear robust.

[13] Portfolio investment is treated as endogenous, implementing the result of a Hausman test. We did not add any additional instruments to [4] so as to single out the impact of including portfolio investment with the corresponding change in the size and composition of the sample. Adding the third lag of the linear and the non-linear portfolio investment to the instrument list did not make much difference to the overall results, but reduced the number of observations by another 31.

Table 2. Further panel data results for exchange rate fluctuations

Dependent Variable: RE_{it}^{a}

	[5]	[6]
$RE_{i,t-1}^{a}$	0.1605460 (1.6)	0.3009190 (3.3)
$REDT_{i,t-1}$	-0.1926180 (5.4)	-0.1165850 (4.1)
$GDP_{it}^{b,c}$	-1.9758300 (2.3)	-1.8902300 (2.0)
$FXIMP_{it}^{a}$	-0.0043740 (3.1)	-0.0048044(3.2)
IR_{it}^{a}	-0.0000009 (40.2)	-0.0000009 (16.5)
EX_{it}	0.0054852 (1.8)	0.0077654 (2.7)
$CRE_{i,t-1}^{a}$	0.2265000 (1.2)	-0.0320613 (0.1)
$CREDT_{i,t-1}$	0.0916476 (0.2)	-0.3142750 (0.7)
$CEXP_{i,t-1}^{a,b}$	-0.0019721 (2.8)	-0.0004018 (0.3)
$CFX_{i,t-1}^{a,d}$	-0.0000088 (1.8)	-0.0000066 (2.4)
$CFXIMP_{i,t-1}^{a}$	-0.0000024 (2.6)	-0.0000027 (2.5)
$CCOM_{i,t-1}^{d}$	0.6698610 (2.4)	0.4244910 (1.9)
$CIR_{i,t}^{a}$	1.8e-018 (27.4)	2.0e-018 (15.9)
$HINFB1000_{i,t}$	0.0130590 (4.0)	
$PORT_{i,t}^{a,b}$		-0.0000272 (2.2)
$CPORT_{i,t-1}^{b}$		-1.1e-011 (2.4)
No. of observations	5323	4192
Standard Error	0.047	0.042
AR(1)	-0.670	-0.427
AR(2)	-1.081	-0.750

Note: T-statistics in parentheses are based on robust standard errors. Fixed effects and year dummies are included in all regressions. RE, REDT, GDP, EXP and COM are in natural logarithms. [a] First differenced. [b] Deviation from trend of twelve-months per cent change. [c] Differenced twice. [d] Twelve-months per cent change (annual growth). See table 1 for further information.

The standard error of all models is very low, indicating that the explanatory variables account for almost all of the variation in exchange rate fluctuations in our sample of emerging market economies. Instrument validity is usually tested with a Sargan test of the overidentifying restrictions. This essentially tests whether the correlation between the instruments and the regression errors is small. Since the Sargan test statistic positively depends on the number of observations and on the R^2 of the OLS regression of the residuals on the instruments, the test can easily fail in very large samples, where the test value may be high due to the number of observations even when the correlation between the errors and the instruments is negligible. Hence we argue that in the case of large samples such as ours, the actual correlation of the instruments with the errors is the relevant magnitude to decide on instrument validity so as to ensure reliability of inference procedures. The R^2 of the OLS regression of the residuals on the instruments falls between 0.023 and 0.027 in the models in table 1 and between 0.042 and 0.027 in table 2, thus strongly supporting the instrument sets. Serial correlation in the residuals also is clearly not a problem. The estimates of the standard errors do therefore not suffer from the bias detected by Berg and Coke (2004) for various binary choice models.

5. Conclusions

The major objective of this paper was to test for the presence of non-linearities in the data generation process underlying real exchange rate changes in emerging markets. Potential non-linearities have so far been neglected in the panel data work on the determinants of currency crises. Many of the emerging market economies however have only recently been developing more advanced financial markets and exchange rates, for example, so they experience rapid growth, having started from a position far away from equilibrium. This provides an ideal opportunity to test for non-linear properties of exchange rates, which we do explicitly by including non-linear terms into our econometric model.

We also extend the current literature by undertaking the analysis using normal regression techniques which allow an assessment on the determinants of large as well as small movements in emerging markets exchange rates. Most of the literature on currency crises employs binary choice techniques such as Logit or Probit models to explain crisis events in a variety of country panels. While these types of models have the advantage of assessing the probability of a crash, they rely on certain pre-defined criteria of what is seen as a 'crisis' event. The nature of these models also implies that they explain only large movements in the dependent variable, while an empirical model in general would attempt to explain all movements in the variable of interest.

We estimate an econometric model of exchange rate changes, using a unique data set of macroeconomic and financial monthly data for a panel of 32 emerging market economies over the period 1985-2002. The analysis incorporates variables from most categories of indicators identified by the theoretical and empirical currency crises literature in our analysis and also considers additional variables such as portfolio investment whose impact has rarely been tested for so far. Our results indicate that foreign exchange reserves, GDP, and domestic interest rates are important determinants of exchange rate fluctuations in tranquil times. High export correlation with a country experiencing large devaluations of its currency seems to intensify the risk of crisis contagion. Moreover, we find evidence of an error correction mechanism with respect to exchange rate deviations from trend, which ceases to be effective in situations of a looming currency crisis. Evidence suggestive of asymmetries is also found with respect to the effect of interest rate increases which tend to be destabilizing in turbulent times. Regarding the major objective of our analysis, we detect the presence of significant non-linearities in the data generation process underlying real exchange rate changes in emerging markets. These mainly stem from fluctuations of foreign exchange reserves as a ratio to imports, export growth as well as changes in global price pressures and interest rates. A range of sensitivity tests confirm our main results.

Data appendix

This appendix gives a description of the data used and their main statistical source. The original sample period is January 1985 – December 2002.

Countries:

Asia: China, Hong Kong, India, Indonesia, Korea, Malaysia, Pakistan, Philippines, Singapore, Sri Lanka, Thailand;

Latin America: Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Peru, Venezuela;

Middle East: Egypt, Israel, Jordan, Kuwait;

Eastern Europe: Hungary, Poland, Russia Turkey;

Africa: Kenya, Morocco, Nigeria, South Africa, Zimbabwe.

Variables:

RE – Real effective exchange rate, monthly series, seasonally adjusted. Missing values obtained by applying growth rates from the respective IMF series. The growth rates of the overlapping periods essentially match, while the IMF data are available only for a smaller subset of our country sample. The growth rate of the US-$ market exchange rate (IMF) was applied where full data for an effective rate were unavailable (one country). US-$ rates used over the whole period where no effective rates were available at all (four countries). Nominal rates adjusted for inflation using the respective CPI's (IMF), which were seasonally adjusted using a geometric moving average.

GDP – Real gross domestic product, World Bank, annual series interpolated to monthly data by natural cubic splines.

FDI – Net foreign direct investment, World Bank. Missing values obtained from UNCTAD net series and from IMF net series as calculated from inflow and outflow data, as available. Growth rates applied where absolute data values of overlapping period differed between the two sources. Annual data then interpolated as for GDP.

PORT – Net portfolio investment, World Bank. Missing data obtained from IMF as calculated from inflow and outflow data, where available. Growth rates applied where absolute data values of overlapping period differed. Annual data then interpolated as for GDP.

EXP – Exports of goods, IMF, monthly data. In-between values missing for less than a full year were interpolated using growth rates of the corresponding World Bank series (monthly data obtained from annual series as for GDP). Merchandise goods series used in absence of total goods series (two countries). Annual growth rates of the monthly series were applied, which in absence of any information to the contrary assumes the same seasonal pattern as in the year preceding or following the interpolated values. The series were then seasonally adjusted as for CPI. Where available, missing data at the beginning or end of the sample period were then interpolated onto the adjusted series by applying the monthly World Bank series' growth rate. (For two countries, the IMF data were available for part of 2001 and 2002 but missing for more than a full year prior to that, so the missing observations were treated as end data, where the interpolation takes account of the actual monthly data.) Growth rates were applied to the first/last genuine data point when the series followed a non-stationary pattern in the corresponding year and to the average value of the year when the data followed a stationary pattern.

FX – Foreign exchange reserves, IMF, monthly data. Missing values interpolated as for GDP, using information from quarterly rather than annual data where available (four countries).

FXIMP – Ratio of foreign exchange reserves to imports. Imports data obtained as for exports.

BUDR – Ratio of government budget balance to GDP, World Bank. Missing values of budget balance series interpolated using information from corresponding series from the IMF or national sources. Annual data then interpolated as for GDP. For four countries, nominal GDP (NGDP) was not available in the first few years (zero due to large units or missing), so the budget ratio was interpolated from the annual World Bank figures as for GDP. The latter series could not be used for the entire sample, as for some countries information on alternative genuine data for use in interpolation were available only for the budget balance levels data.

DEBTR – Ratio of public foreign long-term debt to total foreign long-term debt, World Bank. Annual data interpolated as for GDP. Where the spline exceeded 1 as a result of a ratio equal to one in some earlier years, the annual figure was used as a flat rate for the respective year, and monthly data were interpolated using a centred moving average (two countries). Data missing over the whole sample period were set to zero (four countries).

IR – Interest rates, IMF, monthly data. For two countries, short periods of missing in-between data interpolated from the monthly data by natural cubic splines. Real interest rates obtained using monthly data on annual inflation rates from the IMF. For two countries, inflation data were missing for the first few years and interpolated using information on the corresponding monthly series from national sources and on the interpolated monthly World Bank series, respectively.

M3 – Broad money (M3) for the former OECD countries excluding high-inflation countries, OECD, monthly data, seasonally adjusted. Deflated by the corresponding CPI, which was seasonally adjusted as before.

COM – Global non-fuel commodity price index, IMF, monthly data. Seasonally adjusted as for CPI.

HINFA – Inflation acceleration dummy variable equal to one if annual inflation rose by 100% or more relative to the previous month, zero otherwise.

HINFB100 – High inflation dummy variable equal to one if annual inflation exceeds 100%, zero otherwise.

REG05 – Regional contagion dummy variable equal to one if the real effective exchange rate as measured in logarithms depreciated by 5% or more in any country in the region other than the country in question in the last three months, zero otherwise.

EX0505 – Trade contagion dummy variable equal to one if the real effective exchange rate depreciated by 5% or more in any country the annual export growth correlation of which with the country in question exceeds 50%.

C… – Variable in question cubed.

Nominal series were deflated using the GDP deflator (DGDP) unless mentioned otherwise. DGPD was obtained from GDP and NGDP. For four countries, NGDP data were either missing for the first few years (or zero due to large units) or very close to zero, resulting in a negative spline in the first years of genuine data. The spline was therefore replaced by the annual data average as a flat rate for the whole year. Monthly data were interpolated applying a centred moving average backward from the first point of the non-flat data. In order to be able to apply the interpolation to the beginning of the sample where data were missing (or zero), the flat rates were applied backward, scaled by the growth rate of the first two flat rates based on genuine data in the absence of any information to the contrary.

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