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Exchange Market Pressure in India

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EXCHANGE MARKET PRESSURE IN INDIA

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Abstract:

In this paper, we empirically investigate the episodes of currency market stress/crisis in India during the period 1992 – 2012 with the help of a monthly EMP index for India constructed for this period. For the purpose of this paper, we define currency market stress as "extreme pressure" in the currency market, while a currency crisis is defined as a period of two or more continuous and persistent stress in the currency market. We analyse the distribution of the extreme values of the EMP index by using Extreme Value Theory (EVT) and utilize the knowledge of the extreme values of our EMP index to identify currency market stress in India during this period. We argue that EVT provides a better identification of the stress events than the conventional methodologies.

JEL classification: C10, F31, G15

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1. INTRODUCTION

Exchange rate fluctuations have important implications for macroeconomic management as they impact key variables such as trade balance, domestic output, unemployment and inflation. Understanding exchange (currency) market pressure is important for effective management of the macro economy, particularly for emerging economies like India. A country's exchange rate may come under pressure due to selling pressures on the domestic currency or, alternatively, due to excess demand for foreign currency. In the presence of any such pressure, the monetary authority has two policy choices, viz., either to allow the market forces to work without intervention or to intervene in the market to defend the domestic currency. In the absence of any intervention by the authority, the domestic exchange rate is allowed to depreciate in accordance with the prevailing market conditions. When the monetary authority intervenes to defend the domestic currency, it can do so either by selling international reserves to meet the demand for foreign currency or by increasing interest rates to attract capital inflows. India uses a combination of these three policy options to absorb pressures in the currency market. An appropriate understanding of any currency market pressure would then entail an understanding of these three aspects of the pressure – exchange rate depreciation, fall in the foreign exchange reserves (henceforth reserves) and rise in the interest rate. If one were to look at only exchange rate movements to identify periods of pressures on the currency, it would only capture pressures on the currency by depreciating the domestic currency. In order to capture all aspects of exchange market pressure, a composite measure known as Exchange Market Pressure (EMP) index is used in the literature. The EMP index incorporates all these three factors into one single number and thus helps identify currency market pressures even when policy measures prevented devaluation and/or an eventual crisis.

In this paper, we attempt to empirically investigate the episodes of currency market stress/crisis in India during the period 1992 – 2012 with the help of a monthly EMP index for India constructed for this period. For the purpose of this paper, we define currency market stress as "extreme pressure" in the currency market, while a currency crisis is defined as a period of two or more continuous and persistent stress in the currency market.

We analyse the distribution of the extreme values of the EMP index by using Extreme Value Theory (EVT) and utilize the knowledge of the statistical distribution of extreme EMP index values to identify currency market stress in India during this period. We argue that EVT provides a better identification of the stress events than the conventional methodologies.

This paper contributes to the sparse academic research on currency market pressure in India. In the Indian context, few studies have used EMP index but in context other than to analyze currency market pressure, the focus of this paper.[1] Further, these studies use an EMP index that is based on only two factors of currency market pressure, viz., change in exchange rate and fall in the forex reserves – thus ignoring interest rate hikes which forms a major component of intervention policies for the Reserve Bank of India (RBI) during depreciation episodes.[2] In this paper, we construct a three variable EMP index and thus improve on the previous attempts. The more important contribution of this paper lies in the use of an improved methodology based on Extreme Value Theory (EVT) to identify stress situations. We discuss this methodology and its merits over conventional methodologies in Section 4.

The results of this analysis can be used to enhance our understanding of the nature of exchange market pressures in India. Statistical knowledge of the distribution of extreme values of the EMP index thus computed can contribute towards building up of an early warning mechanism to prevent currency crisis in India. Our empirical methodology is able to identify the stress events in the Indian currency markets which corresponded well with actual pressure episodes, such as the East Asian crisis of 2007 and the recent global financial crisis. During the period of study, there were few occasions when the stress persisted for two months, indicating the advent of a crisis-like situation. However, these did not translate into full-blown "currency crisis" as they did not persist beyond a period of two months.

The rest of the paper is organised as follows: Section 2 defines the EMP index used in this study. Section 3 presents the evolution of EMP index in India. In Section 4, we describe the methodology for defining a stress situation by using EVT. Section 5 presents the results with some analysis. Section 6 concludes.

Section 2: EMP index

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[1] Eg., Baig *et al*. (2003) uses EMP to study RBI's intervention activities and Sengupta and Sengupta (2012) uses it to analyse how RBI manages of capital flows.

[2] See, eg., Sengupta and Manjhi (2011) that point out that depreciation episodes in India were mostly associated with the Reserve Bank of India (RBI) tightening monetary policy by raising interest rates and the statutory reserve ratio.

We follow the literature on EMP index to construct a three variable EMP index for India, as given below.[3]

$$EMP_t = e_t - \frac{\sigma_e}{\sigma_r} r_t + \frac{\sigma_e}{\sigma_i} i_t \qquad (1)$$

Where,

e_t = relative change in nominal exchange rate of Indian rupee against the US Dollar in month t

r_t = relative change in the ratio of gross forex reserves to narrow money (or reserves-to-M1) in month t

i_t = relative change in interest rate in month t

σ_e, σ_r and σ_i are the standard deviations of e_t, r_t and i_t respectively.

The EMP index, as given above, is a weighted average of e_t, r_t and i_t. The first component, e_t, reflects exchange rate movements. The second component r_t measures changes in the forex reserves vis-a-vis the total supply of narrow money, M1.[4] The third component i_t reflects the movements of interest rates in Indian economy. In this index, the weights for reserves-to-M1 and interest rate components are given by the relative size of their respective standard deviations against that of the exchange rate component.

The EMP index thus constructed serves as a useful measure of conditions in the foreign exchange markets, with changes in the index over two time points indicating an increase or decrease in exchange market pressure. A rise in value of EMP index reflects stronger selling pressure on the domestic currency or net excess demand for foreign currency.[5] The currency market is said to be under “stress” if there is significant increase in the EMP index. The question of how large should the value of EMP index be so as to term it as a ‘stress’ or ‘crisis’ has been addressed variously in the empirical literature, which is detailed in a later section.

[3] The EMP Index, first developed by Girton and Roper (1977), initially used two variables – exchange rate and reserves. Kaminsky et.al. (1998), Kaminsky and Reinhart (1999), and Glick and Hutchison (2001) followed this and used a two variable EMP index. In subsequent development, the third variable, interest rate, was incorporated (Eichengreen et. al., 1994, 1995) to reflect that the central bank may also respond to excess demand for foreign currency by raising interest rates.

[4] In the India context, narrow money, also called M1= Currency with the public +Demand deposits with the banking system + ‘Other’deposits with the RBI.

[5]Negative value of the EMP index implies large appreciation or large increases in reserves or large fall in interest rates, which are considered fundamentally different from depreciation pressure (or crises situations) that we are dealing with in this paper.

In the following subsection we provide a brief description of the components of the EMP index defined in (1). The data used for each component are from the Reserve Bank of India (RBI)'s Database on Indian Economy (DBIE).[6]

2.1. Exchange Rate of Indian Rupee

Figure 1 presents the movements of the monthly average exchange rate of rupee against the US Dollar and the movement of relative change of these exchange rates (e_t) over the period of study, 1992-2012. These figures depict the evolution of India's exchange rate policies since 1992. Prior to 1992, the exchange rate regime of India was that of a basket peg wherein the exchange rate for Indian rupee was determined in terms of a weighted basket of currencies of India's major trading partners.[7] For a brief period between March 1992 and February 1993, a Liberalised Exchange Rate Management System (LERMS), consisting of a dual exchange rate system was adopted.[8] With effect from March 1, 1993, a managed float regime regime was introduced wherein the exchange rate was allowed to fluctuate according to the market with RBI intervening in the market whenever necessary. While the *de jure* (i.e., official) exchange rate regime in India is that of managed float since 1993, the *de facto* (actually observed) exchange rate regime varied overtime. For example, the International Monetary Fund (IMF)'s 'fine classification' found various *de facto* exchange rate regime in India, ranging from a pegged regime, crawling peg regime and crawling band regime during 1992 – 2010.[9] Empirical research by Patnaik et al. (2011) also found distinct *de facto* regimes during 1991 – 2010, varying between a period of *de facto* peg of the Rupee to the Dollar till September 1998 then *de facto* a basket peg since April 2004; after March 2007 the Rupee was found to be further flexible (Patnaik et al., 2011).

The second column of Table 1 provides some descriptive statistics of e_t, first component of our EMP index. The series is found to have ranged between a minimum of -6.1 and a maximum of 6.8 during the persiod of our study, with an overall mean of 0.26 and a standard deviation of 1.69. The series is positively skewed and leptokurtic. The Jarque-Berra statistic shows that the series is not normally distributed. The e_t series is found to be a stationary time series, having

[6] The data was retrieved from http://dbie.rbi.org.in/DBIE/dbie.rbi, last accessed on February 1, 2013.
[7] The exchange rate during this period was managed mainly for assisting imports into India.
[8] LERMS was a transitional mechanism that required Authorised Dealers (ADs) to surrender 40 percent of their foreign exchange earnings at the officially determined exchange rate. The remaining 60 per cent were converted at the market rate quoted by the ADs.
[9] For more on this, see web link http://www.imf.org/external/NP/mfd/er/index.aspx.

significant serial correlation in mean as well as in variance as shown by the Ljung-Box test statistics.

(Figure 1 here)

(Table 1 here)

2.2. Reserves-to-M1 ratio

The second component of the EMP index reflects the movements in reserves-to-M1 ratio. This ratio is a measure of the adequacy of reserves of a country as to how much the foreign exchange reserves cover the most liquid money supply (M1). Thus, this ratio indicates the extent to which the Central Bank can honour the total local currency in circulation in the event of a capital flight from the domestic currency market. In this sense, the reserves-to-M1 ratio measures the potential monetary effects of reserve losses in the wake of a crisis situation.

(Figure 2 here)

Figure 2 depicts the movements in reserves-to-M1 and its relative changes (r_t) during 1992 – 2012. We provide descriptive statistics of r_t (second component of EMP index) in the third column of Table 1. The maximum and minimum values for r_t during 1992-2012 were 17.21 and -8.36, with an average value of 0.66 and standard deviation 3.54. Like the e_t series, the r_t series is also found to be positively skewed and highly leptokurtic. The series is a stationary time series, which is not autocorrelated in the mean but displays conditional heteroscadasticity, thus indicating that its variance is autocorrelated.

2.3. Interest rate

The third component of the EMP index reflects the movements in the interest rates. In this study, we use interbank call money market rate as a representative interest rate for the economy.[10] More specifically, we use weighted average interbank call money market rate from RBI's DBIE database. These rates are the simple average of daily weighted overnight (1-day maturity) call money market rates. The daily weighted call money market rates are the weighted

[10] Many studies have found these rates to provide a good approximation of the borrowing costs of the private sector from the banking sector, which is the leading source of short-term finance (Chadha and Dimsdale, 2000; Ford and Laxton, 2000). Further, studies such as Taylor (2000) and Bhattacharya and Sensarma (2005) found high correlation between Treasury bill rate and call money rate so that changes in monetary policy have immediate effects on these segments of the financial market.

average of the rates at which inter-bank transactions take place during a day in the call money market, weighted by the value of these transactions.[11]

Figure 3 presents the graphs of the call money market rate and the relative change of the call money market rate i_t. A look at the graph of i_t reveals that the i_t series is a stable time series, except for ocassional spikes. The descriptive statistics of i_t series, presented in the last column of Table 1 shows that the series is positively skewed and leptokurtic. The Ljung-Box test statistics indicate that the i_t series is non-autocorrelated both in the mean as well as in the variance, thus indicating an iid processs having no time dynamics.

(Figure 3 here)

The basic statistics and time dynamics of the three component series of our EMP index - e_t, r_t and i_t - as presented in Table 1 conforms to the stylised features of financial time series documented in the literature. All the three series are found to be asymmetric (positively skewed) and having excess kurtosis. They are all non-Gaussian as indicated by significant Jarque-Bera test statistic.

Having discussed the various components of our EMP index, we now explain the computation of the index in the following section.

Section 3: Computation of EMP index

As a first step towards building an EMP index for India, we specify the time series dynamics of each of the component series of the index and in a deviation from past studies, use the time varying standard deviation (for the components that display features of conditional heteroscadasticity) in construction of the index. To arrive at an appropriate time series model for the three components we use the standard Box-Jenkins methodology. If the time series specifications of the component series are appropriate and adequate, then EMP index series should be iid, since the components of the EMP index are standardised by the time varying volatilities of the individual components, thus removing any time dynamics from the resultant series.

3.1. Time series dynamics of component series

As reported in Table 1, the e_t series shows autocorrelation with significant Ljung Box Q-statistics suggesting an ARMA process. The squared series also has significant autocorrelation indicating

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[11] We thank Mr G. Mahalingam, Chief General Manager, Financial Markets Division, RBI, for explaining this to us. The DBIE database of RBI, the source of this data, is silent on the definition of weighted call money market rates.

presence of GARCH effect. Using the standard Box and Jenkins methodology, an adequate specification for the rate of changes of exchange rate is found to be an MA(1)-GARCH(1,1) process. The estimated parameters and the diagnostic analysis are presented in Table 2.

(Table 2 here)

As regards the r_t series, it is found to be uncorrelated in the the first moment, but r_t^2 series has significant autocorrelation, suggesting a GARCH process. A specification search leads us to select a GARCH(1,1) process as presented in Table 3, as an adequate representation of the time dynamics of r_t series.

(Table 3 here)

Finally, the i_t series is found to be i.i.d., with no autocorrelation either in the series or in the squared series.

3.2. EMP index for India for 1992-2012

We construct time varying GARCH standard deviations using the models specified above for e_t and r_t series and use them to compute the weights in calculation of the EMP index. Using these estimated volatilities, the EMP index series for India is computed as per the formula (1). The movement of the EMP index series over the period 1992-2012 is presented in Panel 1 of Figure 4. The basic statistics of the series for this period are reported in the second column of Table 4**.** The series is found to be positively skewed and leptokurtic, thus indicating a non-Gaussian distribution. These findings for the EMP index for India are in line with the existing empirical literature for other economies. For example, Pozo and Dorantes (2003) found that the EMP indexes for some Asian, Latin American and European countries over the period 1965-1997 to be positively skewed and highly leptokurtic. Similarly, Pontines and Siregar (2006) also observed similar features for EMP indexes for Indonesia, Malaysia and Thailand for 1985-2003. The EMP index for India that we construct here seems to possess similar features.

(Figure 4 and Table 4 here)

Some standard time series tests for the EMP index series over the full study period 1992—2012 are presented in **Table 5.** The tests for stationary, viz., the Dickey Fuller test and Phillip Pheron test indicate that the EMP series is stationary. The Ljung Box Q-statistic values show that there is no autocorrelation in the series, both at the level as well as at the squared level. Thus, the series is found to have no time varying dynamics in mean and variance.

(Table 5 here)

As depicted by Figure 4, the movements in the EMP index display three distinguishable phases of volatility during the study period. These are as follows: January 1992 – September 1998

(Phase I), a phase of highly volatile EMP index, followed by a relatively calm phase during October 1998 – March 2007 (Phase II) and then back to high volatility again during April 2007 - December 2012 (Phase III).

Panels 2, 3 and 4 of Figure 4 present the EMP index series for these three phases respectively. The basic statistics of the EMP index series during each of these phases are reported in columns 2, 3 and 4 of Table 4. During Phase I, the EMP index varied between a maximum of 13.59 and a minimum of -12.80 with an average value of 0.37 and standard deviation of 3.49. The Indian economy witnessed several episodes of instability during Phase I, including the instability following the 1991 balance of payment (BOP) crisis and that of the Southeast Asian currency crisis during 1997-98. During Phase II (October 1998 to March 2007), the EMP index was negative on an average, with a mean of -0.22, indicating net excess demand for Indian rupee. The EMP index, during this phase, varied between 3.78 and -5.26, with a standard deviation 1.41. Thus, in terms of values as well as volatility, Phase II was a calm period. This was also a period of high growth for the Indian economy. In Phase III, the EMP index is again highly volatile with a standard deviation of 4.15. The index shows spikes in August 2007 and around the sub-prime crisis becoming global during September- October, 2008. It comes down by 2009 and continues to remain at a reasonably low level until the end of 2011. Post December 2011, the index declines again.

Having observed the evolution of the EMP index over the study period, we now address the question of how to identify a stress situation in the currency market. While positive movements of EMP index in general indicate exchange market pressure, only extreme positive movements would reflect a stress situation and persistent stress for two or more consecutive periods in the currency market would indicate currency crisis. How high should be the value of the EMP index for it to be called a stress? In other words, how should we define a threshold value such that any value of EMP index exceeding that threshold may be termed a crisis? We utilise methodologies of extreme value theory to investigate this issue.

Section 4: Methodological issues in defining currency market stress/crisis

Statistically, 'extreme' positive observations of the EMP index can be considered as indicative of intense currency market pressures or stress. Extreme observations are rare in nature; i.e., they occur with a very small probability. Our definition of a currency crisis entails pre-specification of this small probability. If we pre-specify the probability of a crisis event at level p (p being very small), a value of the EMP index that exceeds its $100(1-p)^{th}$ percentile will indicate a stress situation. Thus, with pre-fixed (small) probability p of a crisis, the 100(1-p)th percentile provides a threshold value for the identification of stress/crisis events; if the observed value of the EMP index is more than this threshold, then the currency market can be considered 'under stress'. If the crisis probability is fixed at 0.05 and 0.01, then the 95^{th} percentile and the 99^{th} percentile on the distribution of the EMP index serve as thresholds for identification of a stress situation. These quantiles are located in the tail regions of a probability density function, hence identification of stress events requires the knowledge of the tail behaviour of the EMP index distribution.

Literature has extensively used this threshold-based definition of currency crisis. For example, Eichengreen et al. (1994, 1995) and Bussiere and Fratzscher (2002) defined currency crisis as periods in which the EMP index exceeded twice the standard deviation (2-sigma) above its mean. Kaminsky et. al. (1998) identified a currency crisis when EMP index was above its mean by more than three times the standard deviation (3-sigma). The use of a 2-sigma or 3-sigma limit as crisis threshold is based on the assumption that the underlying distribution of the EMP index is normal; under the assumption of normally distributed EMP index, the probability that the value of the index will exceed the 2-sigma limit is 0.05 and that of the index value exceeding the 3-sigma limit is 0.01.

Thus, the standard deviation based crisis-thresholds are appropriate only if the EMP index series is characterized by well-behaved normal probability density function. However, literature has long established that speculative financial series often display non-normal behaviour with excess kurtosis and asymmetry (Fama, 1965; Blattberg and Gonedes, 1974). The components of the EMP index are all speculative in nature, and hence the EMP index is unlikely likely to follow a normal probability density function. Empirical literature on statistical distribution of EMP indexes have also substantiated that EMP indexes are not normally distributed in general (Pozo and Dorantes, 2003; Pontines and Siregar, 2006). The EMP index that we have constructed here also is found to be non-normal. Thus, use of standard deviation based thresholds would be inappropriate to identify currency crisis events. Recognising the fallacy of using the standard deviation based crisis-thresholds, recent literature on currency crisis has focussed on an EVT based technique for dentifying crisis events (Pozo and Dorantes, 2003; Siregar et. al., 2004; Pontines and Siregar, 2006; Lestano, 2007; Ho, 2008; Cumperayot and Kouwenberg, 2013).

4.1. Extreme Value Theory (EVT)

Extreme Value Theory (EVT) is a special branch of probability theory that deals with the asymptotic behaviour of extreme observations of a random variable. The fundamental result of EVT, known as the Fisher-Tippett theorem or Extremal Types theorem states that if the (appropriately normalised) extreme observations of a sample converges in distribution to a non-degenerate probability distribution, then this distribution must belong to any one of the following three families of distributions: Gumbel (family of distributions with thin tails), Frechet (distributions with fat-tails) or Weibull (distributions with no tail), regardless of the underlying distribution of the random variable. These three families of distributions can be nested together into a single parametric representation, called the 'Generalised Extreme Value' (GEV) distribution. The value of the parameter of the GEV distribution, known as the tail-index, determines whether the limiting distribution of the extreme observations is fat-tailed, thin-tailed or without a tail. A positive value of the tail-index indicates fat-tailed distribution (Student's t, Pareto, marginal distribution of ARCH processes etc), zero value indicates thin tailed distribution (Normal, exponential etc) and negative value of it indicates no tail (Weibull, Beta distribution etc.).

The studies that have used EVT-technique for currency crisis identification so far have followed the approach of Pozo and Dorantes (2003) involving estimation of the tail index by using the so-called Hill-estimatior. The specific assumption under which the Hill-estimaton method is based is that the underlying distribution is fat-tailed.

In this paper, we employ an alternative EVT method, known as Peaks-Over-Threshold (POT) method, for estimating the tail index. The advantage of the POT method lies in the fact that it is applicable to all types of distributions, fat-tailed, thin-tailed and distributions without a tail. Further, we can estimate the tail of the EMP index distribution by fitting a Generalised Pareto Distribution (GPD) to the observations lying beyond a specific threshold. We briefly discuss the POT method in the following sub section.[12]

The POT method is based on the 'Pickand-Balkema-de Haan' theorem that establishes that the distribution of the observations (of a randon variable), in excess of certain high threshold u, (referred to as peaks-over-threshold u) can be approximated by a Generalised Pareto Distribution (GPD), regardless of the distribution of the variable, provided the underlying distribution

[12] For more detailed discussion on this methodology, see McNeil and Frey (2000).

satisfies the Fisher-Tippett theorem. One of the main advantages of this approach is that one is able to identify extreme observations without making any assumptions about the shape of the unknown population distribution. This is a major advantage over the standard-deviation based method, where the underlying distribution is assumed to be normal and the Hill-estimation based method, which is based on the assumption of a fat-tailed distribution.

The GPD is a two parameter distribution, given by

$$H(x)=\begin{cases} 1-(1+\xi x/\sigma)^{\frac{-1}{\xi}}, \xi \neq 0 \\ 1-\exp(-x/\sigma), \xi = 0 \end{cases} \qquad (2)$$

The scale parameter σ is always positive, while the shape parameter ξ can be positive, negative or zero, depending on the underlying distribution. When $\xi > 0$, it imples that the underlying distribution belongs to the Frechet class (a family of fat-tailed distributions), when $\xi = 0$ it implies that the underlying distribution belongs to the Gumbel class (thin-tailed distributions) and $\xi < 0$ implies that the underlying distribution belongs to the Weibull family (distributions without a tail). Thus, the estimated shape parameter ξ of the GPD fitted to the peakes-over-threshold can be used to judge the tail-thickness of the underlying distribution.

In the POT method, first a threshold u is identified to define the beginning of the tail region. Then a GPD is fitted to the 'peaks' or 'excesses' over the threshold u, by using a Maximum Likelihood (ML) procedure. Once the GPD parameters are estimated for the exceedances of a threshold u, the p^{th} quantile on the tail of the distribution of the underlying variable X can be estimated by the following formula:

$$x_p = u + \frac{\hat{\sigma}}{\hat{\xi}}\left\{\frac{n}{k}\left(1-p\right)^{-\hat{\xi}} - 1\right\} \qquad (3)$$

where n is the total number of observations and k is the number of observations above the threshold u, $\hat{\sigma}$ and $\hat{\xi}$ being the ML estimates of the GPD parameters and p the stress probability.

Thus, using the POT approach one can parametrically estimate any tail-quantile of the underlying EMP index distribution. If the stress probability is fixed at 0.05, then the 95^{th}

percentile will serve as the stress-threshold while if it is 0.01, then the 99th percentile will be the stress threshold. Using formula (3), the entire tail region can be estimated.

While implementing the POT approach, the choice of an optimal threshold level u, that defines the start of the tail region, can be a big challenge.[13] The threshold u should be as high as possible for the Pickands-Balkema-de Haan theorem to hold good so that the GPD provides a close enough approximation to the distribution of peaks-over-threshold. However, in practice, too high a threshold would leave us with too few observations for estimating the GPD parameters, leading to high variance in the estimates. This is known in as bias-variance trade-off (McNeil and Frey, 2000) in choosing u. Researchers using POT approach have tackled this challenge in various ways.[14]

Section 5: A POT Analysis of EMP Index of India

In this paper, we consider the largest 20 per cent of our EMP index values to be extreme observations, i.e., the tail-threshold u is chosen at a value such that the probability of the EMP index being higher than this is 0.2.[15] The value of u chosen in this manner is 1.6249. We then fit a GPD to the 'excesses' over u=1.6249 and use the estimated GPD parameters to compute our crisis-thresholds given by 95th percentile (for crisis-probability = 0.05) and 99th percentile (for crisis-probability = 0.01). The results of this estimation are presented in Table 6. As shown in Table 6, the shape parameter of the fitted GPD parameter is found to be 0.2418. The positive shape parameter indicates the EMP index series follows a Frechet distribution, a fat-tailed distribution. This substantiates the results of Tables 4 and 5 that show high excess kurtosis and rejection of the Jarque-Bera test of normality for the EMP index series. The last two columns of Table 6 report the 95th and 99th percentiles on the distribution of the EMP index, estimated by using formula (3). The estimated 95th percentile is 5.07 and the 99th percentile is 10.84. These are the stress/crisis thresholds at 0.05 probability and 0.01 probability of stress/crisis respectively. A value of the EMP index larger than these thresholds would indicate a stress situation at corresponding probability level.

(Table 6 here)

[13] The tail threshold *u* should not be confused with crisis-threshold. The crisis-threshold is a quantile residing much beyond *u* in the tail, and this can be estimated after fitting the GPD to observations exceeding *u* by using the tail-quantile formula given by (3).

[14] See, e.g., McNeil and Frey (2000), Gavin (2000), Neftci (2000).

[15] We use a 20 per cent threshold in the interest of having enough observations in the tail for a good GPD fit, keeping in view the total number of observations we have.

We also use formula (3) to estimate several tail quantiles, for different probability levels p. **Table 7** presents some of the estimated tail quantiles, along with empirical quantiles and the corresponding quantiles of the standard normal distribution. Figure 5 plots the estimated EVT-based quantiles, the empirical quantiles and the corresponding normal distribution quantiles. As seen from both Table 7 and Figure 5, we see that EVT based quantiles fit the empirical quantiles far better than the normal distribution quantiles. Thus, if we were to use the normal distribution based crisis threshold for our EMP index series, then we would end up with a very low crisis threholds, giving rise to a false and overestimated perception of the risk of currency crisis. In other words, a normal distribution approximation of the underlying data generating process for the EMP index series would provide to misleading estimation of extreme quantiles, and accordingly a false notion of stress/crisis.

(Table 7 and Figure 5 here)

5.1. Identifying currency market stress/crisis in India during 1992-2012

As reported in Table 6, the stress threshold at 0.05 probability level is estimated as 5.07 and that at 0.01 level is estimated at 10.84. An EMP index value larger than these thresholds would indicate a crisis/stress situation in the currency market. If our model specification is adequate, then with 252 monthly observations, we expect roughly 13 stress episodes with stress probability fixed at 0.05 and about 3 episodes of crisis situations with a stress probability of 0.01.

Our model is able to identify 11 episodes of stress at 0.05 probability and 3 episodes of stress with 0.01 probability during the period 1992 - 2012. The months of exchange market stress using 95th percentile are as follows: April 1992, May 1992, October 1995, November 1995, November 1997, January 1998, June 1998, August 2007, September-October 2008 and December 2011 (Figure 6). If we define crisis as a sustained period of stress with two or more consecutive stress months, then at a probability 0.05 of stress, we can recognise 3 episodes of crisis-like situation in Indian currency markets, viz. April-May 1992, October-November 1995 and September-October 2008. The 99th percentile identifies January 1998, August 2007 and October 2008 as periods of extreme pressure on the Indian currency.

If we had used normal quantiles to define extreme values of the EMP index we would have got 53 exceedances (at 95 per cent level). Thus, use of the normal distribution based threshold for stress identification would end up identifying an excessive number of periods as stress/crisis, falsely identifying many ordinary market fluctuations as extreme movements, leading to an underestimation of the underlying risk.

(Figure 6 here)

5.2. An analysis of the stress episodes

Having identified the stress episodes as shown in Figure 6, we now analyse these stress episodes in the currency market. We attempt to explain these periods in the context of the economic situations prevailing around the periods and also look at the contribution of each of the three components of our EMP index during these stress episodes.

In Table 8, we present the stress episodes in India's currency market during 1992 - 2012 as identified by our study, along with a decomposition of the extreme EMP index during these stress periods by its three components. As seen this table, while the exchange rate and reserves-to-M1 components were major determinants of high value of EMP index in most of the extreme periods, high interest rates seemed to be more responsible for the high EMP value during the months of November 1995, January 1998 and August 2007.

(Table 8 here)

We now turn to the specific periods of stress as identified by our study.

April-May 1992

In April and May 1992, the EMP index breached the 95 per cent threshold, and attained a value of 6.63 and 5.61 respectively. The exchange rate component contributed 75 per cent and the interest rate component contributed 20 per cent to the value of the EMP index in April 1992. In May 1992, however, reserves-to-M1 and interest rate components contributed 98 per cent and 36 per cent respectively to the high EMP index value. It is interesting to note that in May 1992, the exchange rate actually appreciated by about 2 per cent. The appreciating exchange rate contributed -34 per cent towards the EMP index. Thus, the exchange rate component helped, to some extent, in stemming the pressure in May 1992.

The continued pressure for two consecutive months in the currency market should be seen in the context of major changes taking place in the Indian economy around this period. India had a severe BOP crisis in mid-1991. The Indian rupee that was pegged earlier was floated partially in March 1992. The market reaction to a crisis-ridden economy was reflected in the steep depreciation of the Indian rupee in April 1992, and RBI's intervention to this pressure was reflected in the fall in reserves-to-M1 and a hike in the interest rate in May 1992.[16] This continued exchange market pressure for two consecutive months indicates a crisis-like situation; however it did not prolong for more than two months.

October-November 1995

The EMP index value exceeded the 95 per cent threshold in October 1995 (with a value of 9.99) and November 1995 (with a value of 7.61). The large value of the EMP index in October 1995 was contributed by a depriciating rupee (that contributed to about 41 per cent towards the EMP index), a falling reserves-to-M1 (contributing another 41 per cent towards the high EMP) and a rising interest rate (contributing 18 per cent towards the high EMP index). In November 1995, however, it was the high interest rate that contributed mostly (88 per cent) to the high value of the EMP index, the contribution of the exchange rate movement was only 6.2 per cent while that of the reserves-to-M1 component was 5.9 per cent.

During this period there was an increase in India's current account deficit. India's current account deficit as a percentage of GDP increased from 0.4 per cent in 1993-94 to 1 per cent in 1994-95 and further to 1.7 per cent in 1995-96. This period was also characterized by sharp movement in exchange rate, as reported in the Report on Currency and Finance, 2005-06 of RBI, as a result of an appreciation of the US dollar against other major currencies.

November 1997, January 1998 and June 1998

The EMP index value was 5.54 in November 1997, 13.59 in January 1998 and 5.57 in June 1998 breaching the 95 per cent threshold in all of these months and the 99 per cent threshold in January 1998. The reserves-to-M1 ratio and exchange rate components contributed 50% each to the high value of the index during November, 1997. In January 1998 it was the interest rate component that determined the high value of EMP index (112 per cent), in June 1998, the exchange rate component contributed 79 per cent to the value of the index.

The exchange rate was stable in the range of Rs. 35.50- 36.00 per US dollar from April 1996 to mid-August 1997. However, during the year 1997-98 and first half of 1998-99, the contagion effect of the South-East Asian currency crisis, coupled with some domestic factors exerted some

[16] The Indian economy also witnessed a major stock market scam in April 1992 in the Bombay Stock Exchange that eventualy led to several reforms in India's Capital Market, including the establishment of the highly sophisticated National Stock Exchange (NSE) in 1992.

pressure in the currency market in India. There was significant volatility in the Indian foreign exchange market from mid-August 1997 to January 1998 and during May-June 1998.[17] Market sentiment weakened sharply from November 1997 onwards in reaction to intensification of the crisis in the South-East Asia.[18] In November 1997 there was 3 per cent depreciation in the rupee and 4 per cent fall in reserves-to-M1 ratio. In January 1998, the interest rates rose by 250 per cent, contributing 112 per cent to the high value of EMP index.

Post the Asian crisis period, particularly during May to August 1998, the Indian economy faced certain other challenges like economic sanctions imposed by several industrial countries, suspension of fresh multilateral lending, downgrading of country rating by international rating agencies and reduction in investment by foreign institutional investors (FIIs).[19] Moody's downgraded India's sovereign rating from investment to non-investment grade and Standard & Poor's changed the non-investment grade outlook for India from stable to negative. Following these developments, the exchange rate of the Rupee depreciated from Rs. 39.66 per US dollar in April 1998 to Rs. 42.26 to the US dollar in June 1998.[20] The RBI sold USD 1590 mn worth of reserves in November 1997 and USD 1627 mn in June 1998 to stem the depreciation pressure on the Rupee.

August 2007

The EMP index reached its all time high value of 21.42 over the study period in August 2007 largely contributed by interest rate hike. The interest rate component of EMP index contributed 105 per cent to this high value of the index; the contribution of the exchange rate component was about 5 per cent. The reserves-to-M1 ratio was rising during this period, implying that it had a cooling impact on the extreme pressure.

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[17] RBI Report on Currency and Finance, 2005-06.

[18] The crisis started in Thailand with the financial collapse of the Thai Baht in December 1994. It spread to most of Southeast Asia and Japan, leading to falling currencies and devalued stock markets and other asset prices.

[19] In May 1998, the Indian Government engineered nuclear tests, inviting widespread sanctions. For example, the US suspended foreign aid, stopped credits or guarantees by US government agencies and prohibited US banks from making loans to Indian Government. All of the G-7 countries and some non-G-7 countries joined the US in opposing new non-humanitarian lending by the IMF, the World Bank, and the Asian Development Bank to India.

[20] RBI Report on Currency and Finance, 2005-06.

The Indian economy witnessed a high inflation episode in 2007. To tame the inflationary pressure, RBI embarked upon several measures to tighten the liquidity in July 2007.[21] This led to a rise in call money rate which rose to 6.31 per cent in August 2007, a monthly a rise of 764 per cent. This, along with 1 per cent depreciation in the rupee due to strong FII outflows, following bearish conditions in the Indian equity market and concerns over subprime lending crisis in the US, led to a high value of EMP index in August 2007.

September-October 2008

EMP index values breached the 95 per cent threshold in September 2008 and both 95 per cent and 99 per cent thresholds in October 2008. While it was the exchange rate component which contributed the most to EMP index value in September, 2008 (95 per cent), it was the reserves-to-M1 (53 per cent) and exchange rate component (50 per cent) which led to high value of the index in October 2008.

The subprime crisis had assumed global proportions by September-October 2008 following the collapse of Lehman Brothers.[22] The impact of the crisis on Indian economy, which was initially subdued, intensified since mid-September 2008. All segments of the financial markets, viz., equity markets, money markets, forex markets and credit markets had come under severe pressure during this period. The Rupee came under pressure with outflow of portfolio investments, higher foreign exchange demand by Indian industrialists seeking to replace external commercial borrowing by domestic financing, and the consequent decline in foreign exchange reserves. There was a depreciation of 6 per cent and 7 per cent in the rupee during the months of September and October 2008, respectively. India's reserves-to-M1 ratio fell by 12 per cent in October, 2008. The EMP index was at a high of 6.42 in September and increased to a value of 13.53 in October, 2008.

RBI intervened to ease the stress in currency markets since November 2008. It sold a net of USD 22450 mn Dollars during September - October 2008 to meet the Dollar demand and prevent the rupee from depreciating further.

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[21] These included the withdrawing of the ceiling of Rs 3,0000 mn on the daily reverse-repo under Liquidity Adjustment Facility (LAF), discontination of the second LAF and raising of the reserve requirements of banks (viz. the Cash Reserve Ratio).

[22] Lehman Brothers Holdings Inc. was the fourth largest investment bank in the USA, before declaring bankruptcy in September 2008. This marked the largest bankruptcy in U.S. history, and is regarded to have played a major role in the unfolding of the global financial crisis of 2008-09.

December 2011

The EMP index was at a high of 8.91 in December 2011 with reserves-to-M1 contributing 57 per cent and exchange rate component contributing 40 per cent to the value.

The year 2011-12 began with concerns over European debt sustainability. Poor growth forecasts in developed countries caused a flight of capital from emerging economies, including India, deteriorating the Indian rupee.[23] The Indian rupee depreciated by 15 per cent in November 2011 and by another 4 per cent in December 2011, reflecting investors' lack of confidence in the Indian economy. The RBI resorted to net sales of Dollars of USD 7809 mn to prevent fall in rupee value.

It is worth noting that each of these identified stress situations in the Indian currency markets was not seen to persist longer than two months following active intervention strategy of the RBI. Hence, the country did not witness a "currency crisis" situation as the term is popularly defined in the theoretical and empirical literature.

Section 6: Conclusion

In this paper, we empirically analyze episodes of stress in India's currency market. We construct a monthly EMP index for India, improving over earlier attempts. We use Extreme Value theory (EVT) to analyse the statistical distribution of the extreme values of EMP index and find that EVT-based methodology provide a better fit to the distribution the extreme EMP values than the conventionally used normal distribution based method. Using EVT, we estimate the thresholds to identify stress episodes in the currency market, with pre-specified probability of stress. We identify 11 episodes of stress with a stress probability 0.05, of which 3 episodes also classify as extreme stress episodes with stress probability 0.01. We discuss these stress episodes in the context of the prevailing economic environment and also present some analysis of the relative contribution of the three factors of EMP index towards the stress. Defining currency crisis as a sustained period of two or more consecutive stress months, we found 3 episodes of crisis-like situation in Indian currency markets, viz. April-May 1992, October-November 1995 and September-October 2008. However, none of these episodes persisted beyond two months, due to RBI's effective management of these extreme pressures. Thus, none of these episodes translate into full-blown currency crisis.

[23] Financial Stability Report of the RBI, December 2011.

The results of this analysis can be used to enhance our understanding of the exchange market pressure in India's currency market. An adequate empirical characterisation of the exchange market pressure is important for providing early warning signals for exchange market stress and thus for its effective management. This study is a step towards that direction.

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Figures and Tables

Figure 1: Movement of monthly average exchange rate of rupee and rate of change in exchange rate

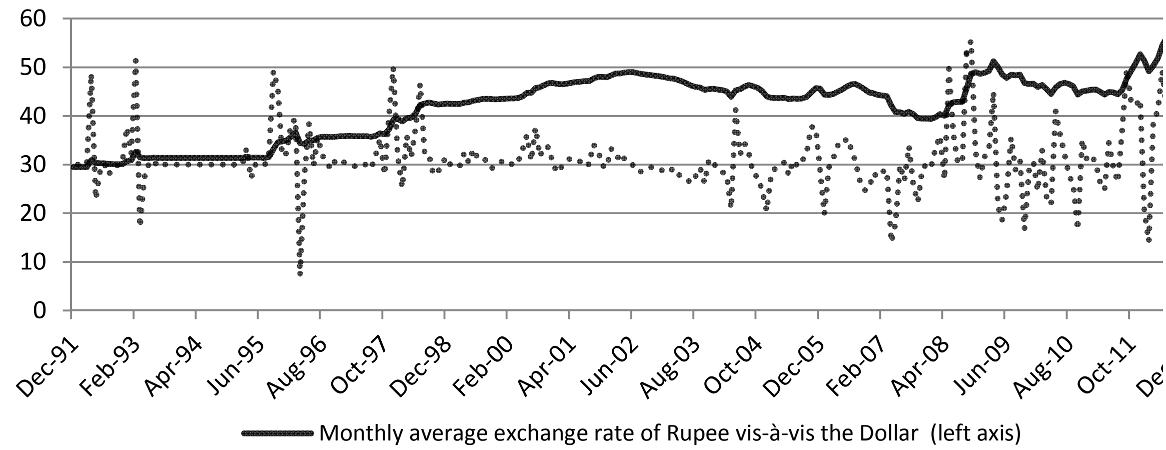

Figure 2: Movements in reserves-to-M1 ratio and its relative changes

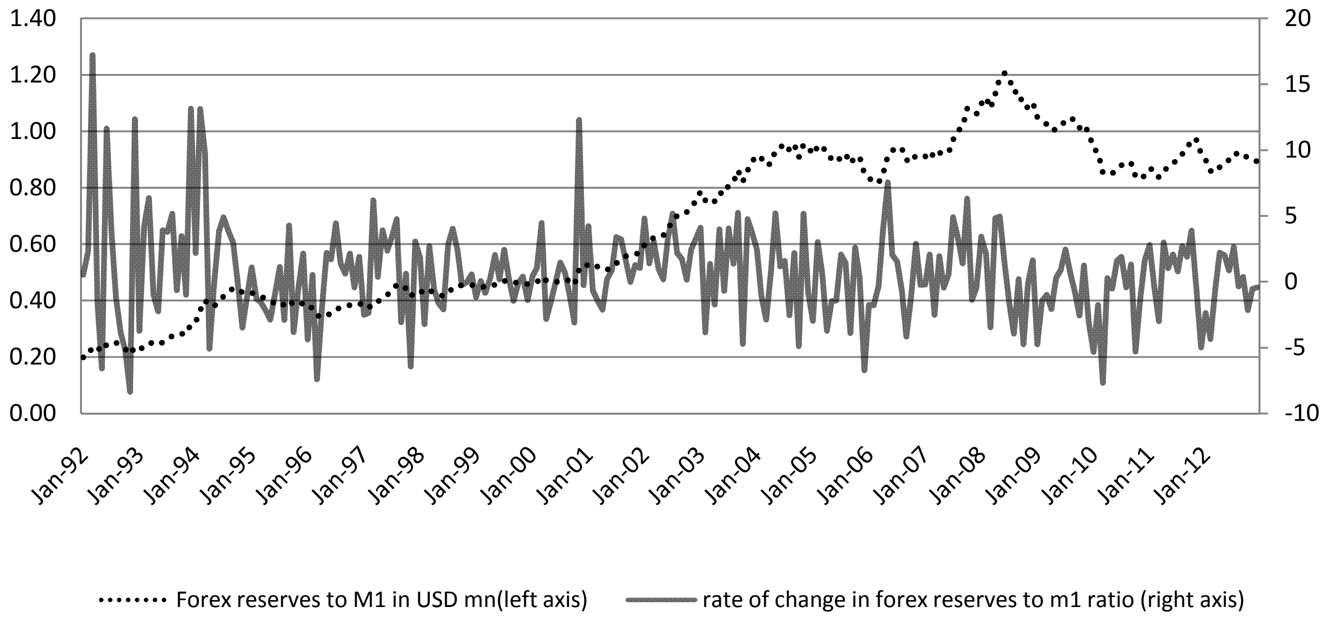

Figure 3: Movement of weighted average call money market rate and rate of change of call money rate

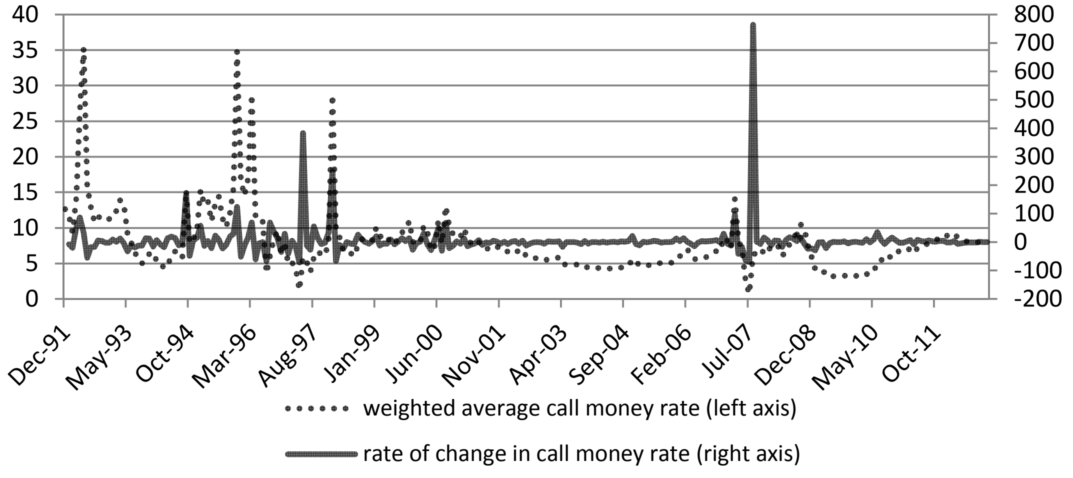

Figure 4: Movement of EMP index series

Panel 1

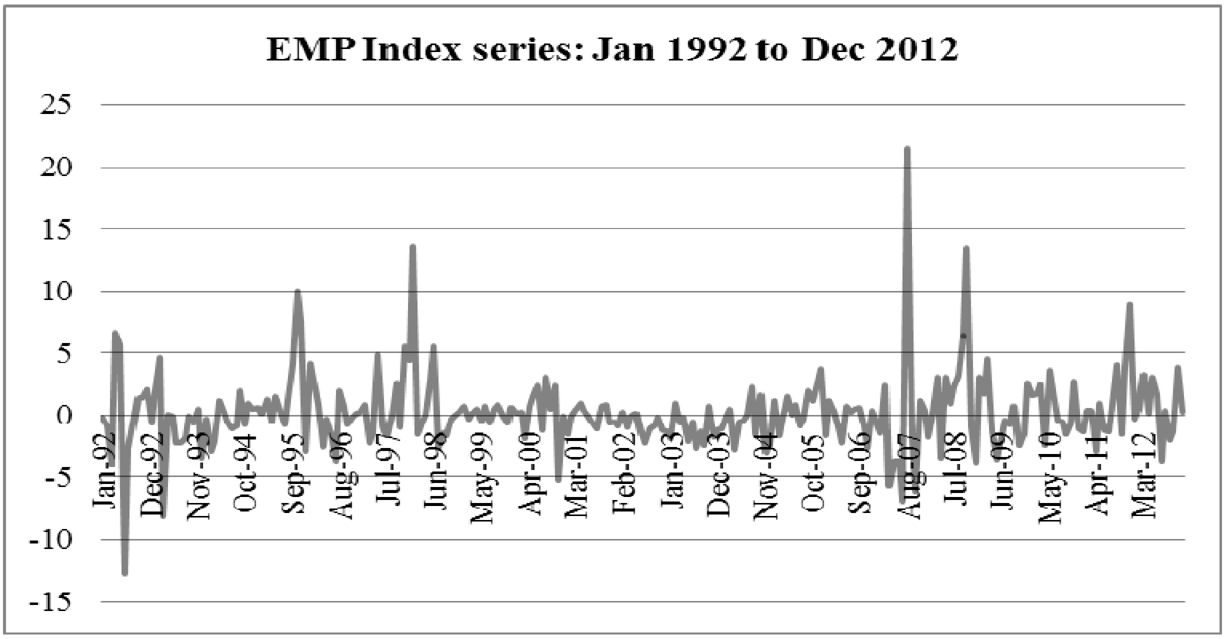

Figure 4: Panel 2

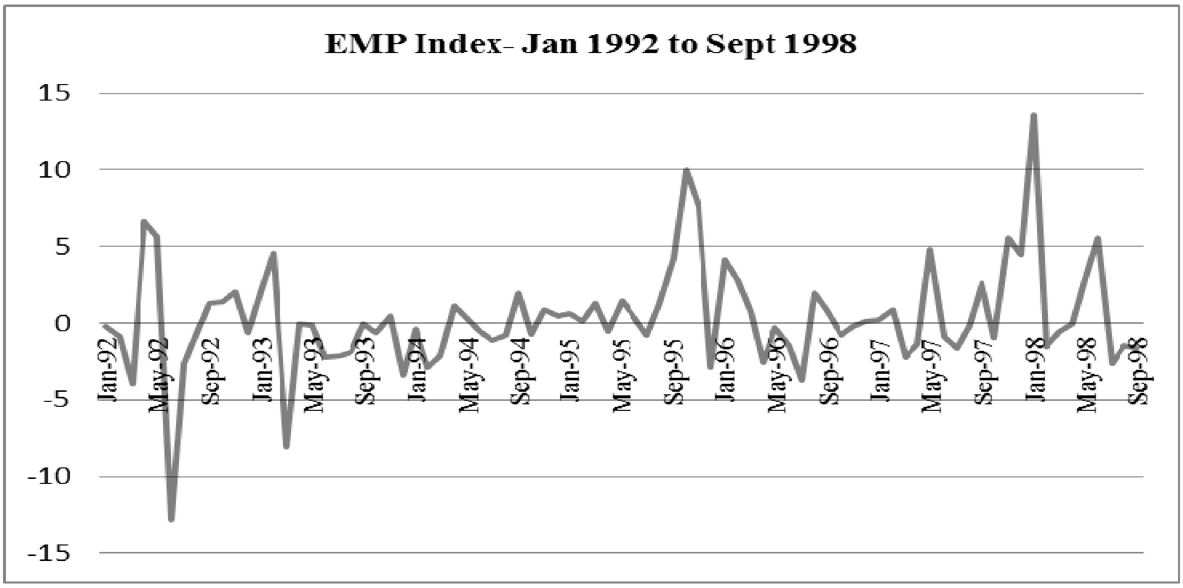

Figure 4: Panel 3

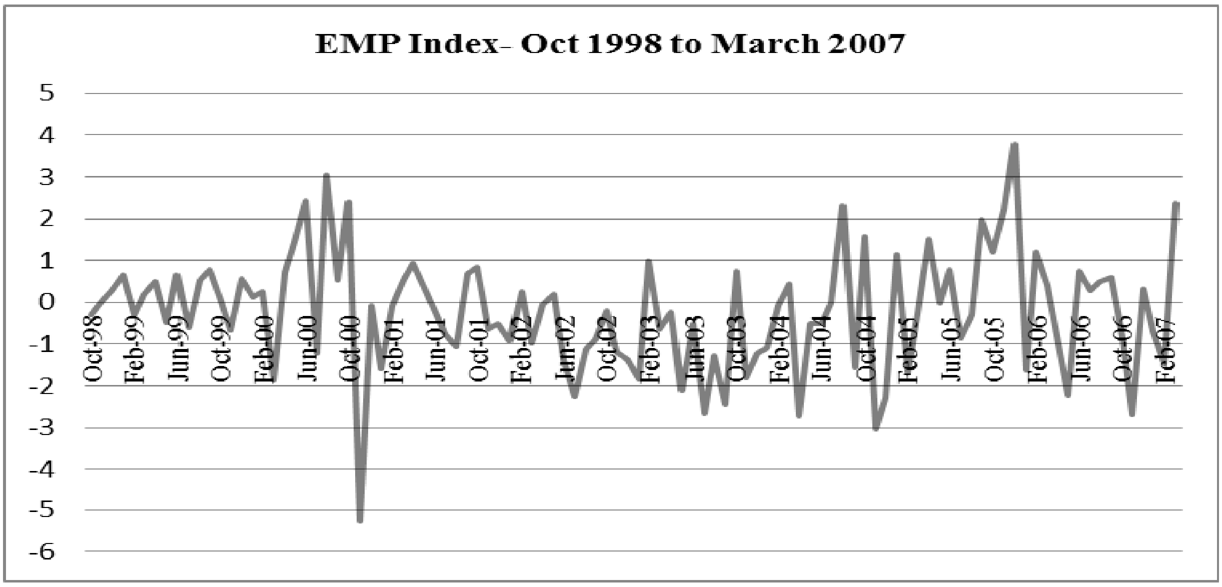

Figure 4: Panel 4

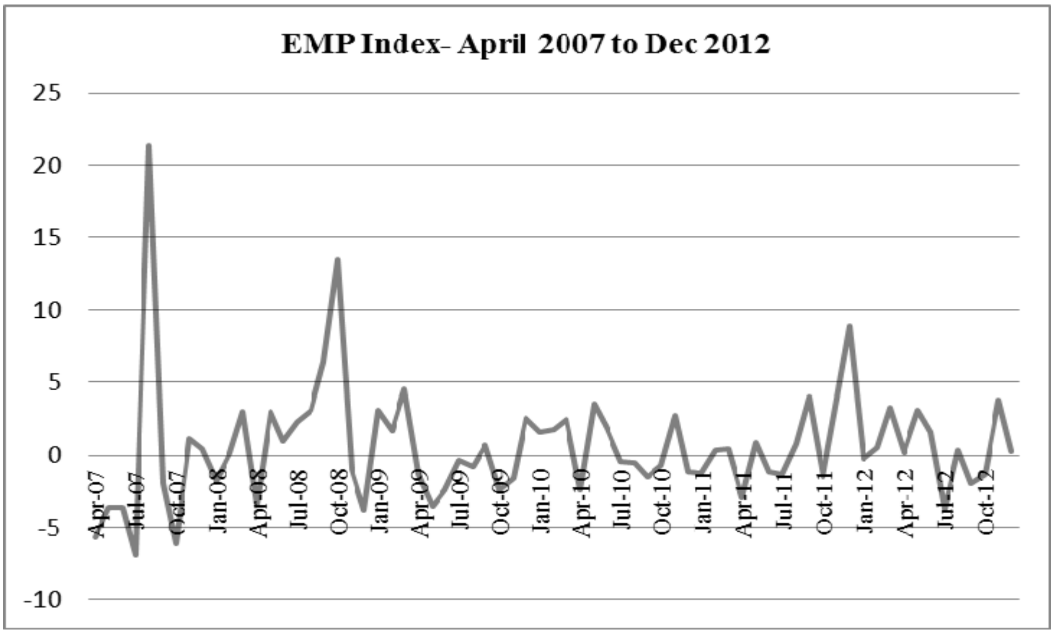

Figure 5: Comparison of empirical and estimated (EVT- based) tail quantiles with normal quantiles

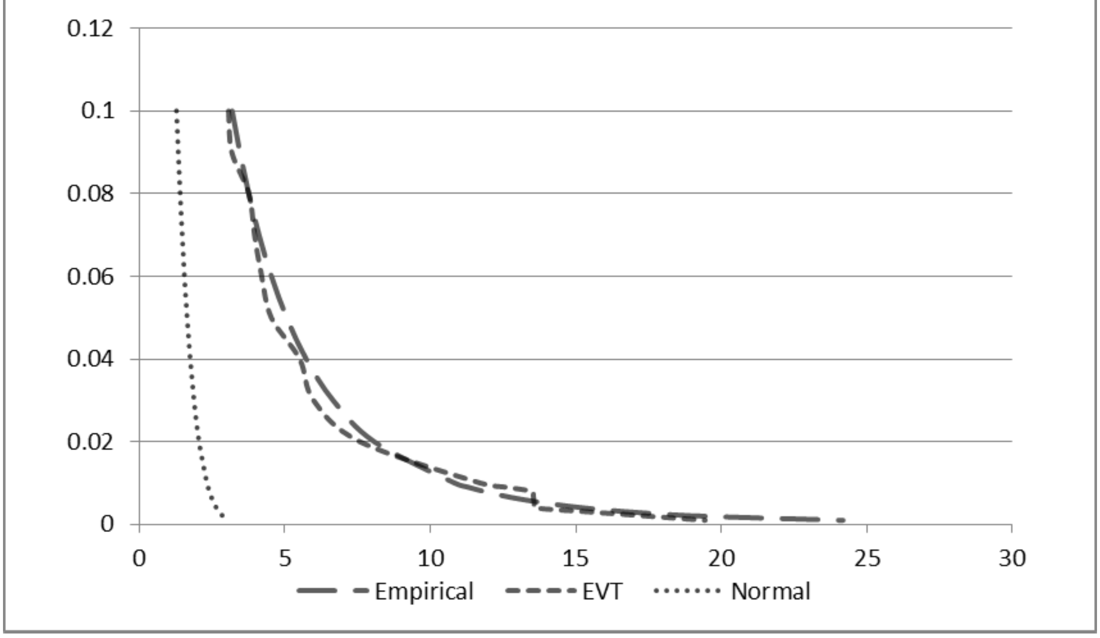

Figure 6: Episodes of Exchange Market Stress: 1992-2012

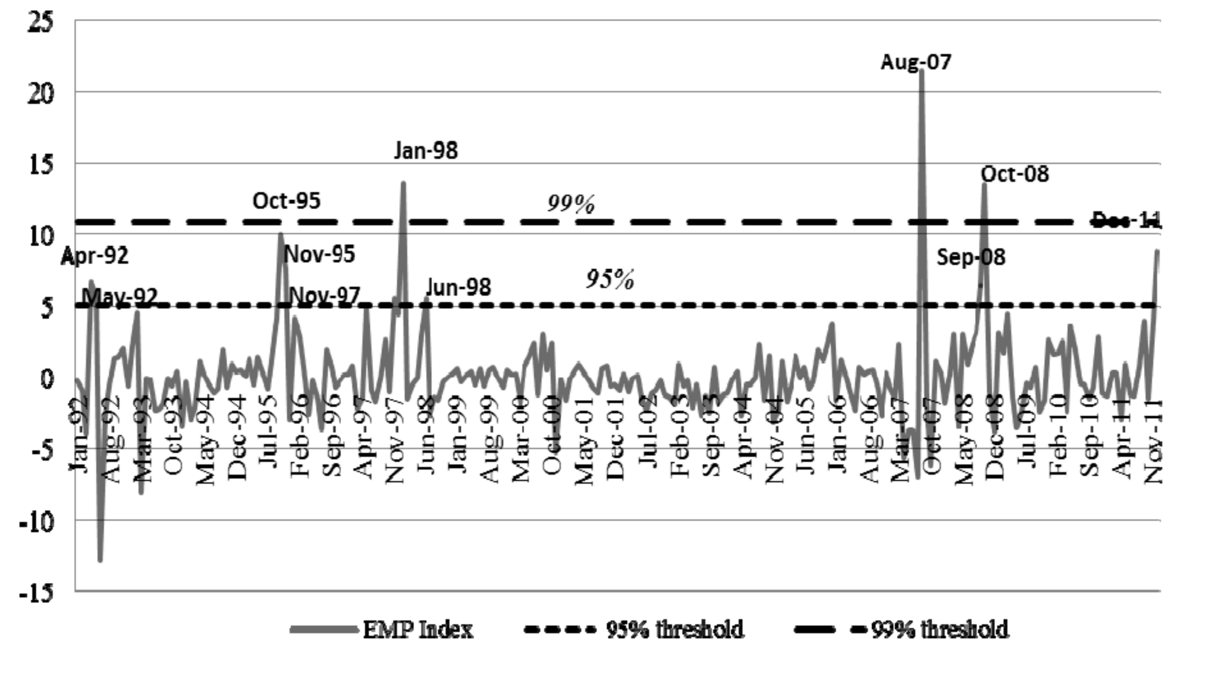

Table 1: Descriptive statistics and time series tests of components of EMP index and the constructed EMP index			
	Rate of change of exchange rate (e_t)	**Rate of change in reserves-to-M1 (r_t)**	**Rate of change of call money rate (i_t)**
Basic statistics			
Maximum	6.786	17.207	764.384
Minimum	-6.076	-8.362	-71.954
Mean	0.259	0.663	6.466
Standard deviation	1.690	3.536	61.182
Variance	2.854	12.503	3743.237
Skewness	0.752	0.868	8.847
Kurtosis	6.299	6.043	101.326
Jarque-Bera	138.08 (0.00)	128.865 (0.00)	104801.4 (0.00)
Stationarity tests			
ADF test statistic	-12.256 (0.00)	-15.554 (0.00)	-17.809 (0.00)
PP test statistic	-12.123 (0.00)	-15.554 (0.00)	-18.162(0.00)
Autocorrelation test			
Ljung-Box Q statistic for series			
Q(20)	54.651 (0.00)	24.429(0.22)	13.84(0.84)
Q(30)	57.432 (0.00)	38.005(0.15)	15.046(0.99)
Q(40)	69.803(0.00)	41.484(0.41)	16.789(1.00)
Heteroscidasticity test			
Ljung-Box Q statistic for squared series			
Q(20)	56.523(0.00)	50.649(0.00)	0.356(1.00)
Q(30)	59.473(0.03)	84.118(0.00)	0.603(1.00)
Q(40)	80.213(0.01)	85.833(0.00)	0.808(1.00)
Notes: *Figures within the parenthesis are p-values			

Table 2: Time series specification of rate of change of exchange rate-MA(1)-GARCH(1,1) model

Parameter	Estimate	Standard Error	p-value
Mean equation			
C	0.132	0.088	0.13
MA(1)	0.267	0.096	0.01
Variance equation			
C	0.472	0.292	0.11
ARCH(1)	0.550	0.189	0.00
GARCH(1)	0.461	0.162	0.00
DW = 1.978			
AIC = 3.668; SIC =3.738			
Q-Stat for residuals:	Q-stat for squared residuals:		
Q(20)=31.588(0.04)	Q(20)=20.69(0.35)		
Q(30)=37.907(0.12)	Q(30)=22.28(0.84)		

Table 3: Time series specification of rate of change of forex reserves to M1 ratio- GARCH(1,1) model

Parameter	Estimate	Standard Error	p-value
C	0.584	0.204	0.00
Variance equation			
C	0.428	0.552	0.44
ARCH(1)	0.038	0.029	0.20
GARCH(1)	0.916	0.067	0.00
DW = 1.929			
AIC =5.298; SIC =5.354			
Q-Stat for residuals:	Q-stat for squared residuals:		
Q(20)=20.465(0.43)	Q(20)=7.867(0.99)		
Q(30)=35.815(0.21)	Q(30)=18.65(0.95)		

Table 4: Basic statistics of the EMPI series over three sub-periods and the full period				
	Full period: Jan 1992 to Dec 2012	**Jan 1992 to Sept 1998**	**Oct 1998 to March 2007**	**April 2007 to Dec 2012**
Maximum	21.416	13.586	3.783	21.416
Minimum	-12.797	-12.797	-5.261	-6.906
Mean	0.201	0.374	-0.219	0.616
Standard deviation	3.078	3.489	1.409	4.150
Variance	9.474	12.173	1.985	17.223
C.V	15.313	9.329	6.434	6.737
Skewness	1.845	0.373	-0.158	2.186
Kurtosis	15.013	7.165	4.113	11.631

Table 5: Standard time series tests for EMP index series: 1992 to 2012	
Jarque-Bera	1658.26(0.00)
Stationarity tests	
ADF test statistic	-15.203(0.00)
PP test statistic	-15.195(0.00)
Autocorrelation test	
Ljung-Box Q statistic for series	
Q(20)	16.67(0.43)
Q(30)	21.33(0.88)
Q(40)	23.44(0.98)
Heteroscidasticity test	
Ljung-Box Q statistic for squared series	
Q(20)	19.41(0.49)
Q(30)	20.98(0.89)
Q(40)	22.03(0.99)

Table 6: GPD estimation results of the EMPI series (right tail)						
Percentage of observations above threshold	**Number of observations above threshold**	**Threshold (u)**	**Shape parameter (ξ)**	**Scale parameter (σ)**	**95th percentile**	**99th percentile**
20 per cent	50	1.6249	0.2418 (0.168)	2.1036 (0.456)	5.0665	10.8422
Figures in the brackets are standard errors of the estimates						

Table 7: Estimated tail quantiles of EMP index series : 1992-2012			
Prob. Level	Estimated (EVT based) quantiles	Empirical quantiles	normal quantiles
0.8	1.608	1.617	0.842
0.81	1.717	1.727	0.878
0.82	1.832	1.932	0.915
0.83	1.956	2.012	0.954
0.84	2.089	2.188	0.995
0.85	2.234	2.329	1.036
0.86	2.391	2.415	1.080
0.87	2.562	2.621	1.126
0.88	2.749	2.789	1.175
0.89	2.959	3.026	1.227
0.9	3.193	3.070	1.282
0.91	3.458	3.181	1.341
0.92	3.762	3.768	1.405
0.93	4.118	3.962	1.476
0.94	4.543	4.209	1.555
0.95	5.067	4.539	1.645
0.96	5.739	5.514	1.751
0.97	6.663	5.992	1.881
0.98	8.078	7.588	2.054
0.99	10.842	11.723	2.326
0.991	11.304	12.612	2.366
0.992	11.835	13.501	2.409
0.993	12.456	13.543	2.457
0.994	13.197	13.557	2.512
0.995	14.111	13.572	2.576
0.996	15.285	13.586	2.652
0.997	16.896	15.519	2.748
0.998	19.364	17.485	2.878
0.999	24.187	19.450	3.090

Table 8: Extreme EMP Index months, its components and contribution (in percentage) of each component to the EMP index value							
Months of extreme EMPI values	**EMPI**	**Components of the EMP Index**			**Contribution of each component to the EMP Index value (in percentage)**		
		Exchange rate	*Forex reserves to M1*	*Interest rate*	*Exchange rate*	*Forex reserves to M1*	*Interest rate*
Apr-92	6.63	4.99	-0.32	1.33	75.26	-4.83	20.06
May-92	5.61	-1.89	-5.49	2.01	-33.69	-97.86	35.83
Oct-95	9.99	4.14	-4.07	1.77	41.44	-40.74	17.72
Nov-95	7.61	0.47	-0.45	6.69	6.18	-5.91	87.91
Nov-97	5.54	2.78	-2.79	-0.04	50.18	-50.36	-0.72
Jan-98	13.59	0.43	2.09	15.26	3.14	15.38	112.29
Jun-98	5.57	4.41	-1.31	-0.16	79.19	-23.52	-2.87
Aug-07	21.42	1.01	2.06	22.47	4.72	9.62	104.90
Sep-08	6.42	6.12	0.10	0.41	95.33	1.56	6.39
Oct-08	13.53	6.79	-7.19	-0.44	50.18	-53.14	-3.25
Dec-11	8.91	3.59	-5.07	0.25	40.29	-56.90	2.81