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Phornchanok Cumperayot

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STABILITY OF THAI BAHT:
TALES FROM THE TAILS*

Phornchanok Cumperayot†

Faculty of Economics, Chulalongkorn University, Thailand.

ABSTRACT

We demonstrate how the EVT-based signalling approach for currency crises can be applied to an individual country with a small sample size. Using Thai historical data, first, we study the tail characteristics of the distributions of two Thai baht instability measures and 21 economic fundamentals. Then, we test asymptotic dependence between the currency instability measures and lagged economic fundamentals. Empirically, we find that the distributions of both currency instability measures and economic variables are heavy tailed. Assuming a normal distribution for the variables tends to underestimate the probability of extreme events. Furthermore, most of the economic variables which are usually used as signalling indicators for currency crises are asymptotically independent of the currency instability measures. Signals issued by these variables are thus not reliable. Nevertheless, the non-parametric EVT approach facilitates the selection of economic indicators with credible signals and high crisis prediction success.

Keywords: Thai baht, Exchange rate instability, Extreme value theory
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† Author's contact address: Faculty of Economics, Chulalongkorn University, Bangkok 10330, Thailand
Tel: +66 2 218 6182 Fax: +66 2 218 6201 E-mail: Phornchanok.C@chula.ac.th

I. INTRODUCTION

According to the International Monetary Fund (2008), promoting economic stability is a matter of avoiding economic and financial crises, which means avoiding large swings in economic activity, high inflation, and excessive volatility in exchange rates and financial markets. In this paper, we propose a way of reducing vulnerability to currency instability by first studying extreme events in the Thai baht market and then identifying the economic factors that are potentially linked to the turmoil in the FX market. Our work mostly resembles the signalling approach initiated by Kaminsky, Lizondo and Reinhart (1998). However, we use extreme value theory (EVT) to search for the leading indicators for extreme movements in the Thai baht market in order to minimise the likelihood of future currency instability.[1]

Unlike in the work conducted by Kaminsky et al. (1998), the thresholds used to define currency instability and economic signals in this paper are selected at the cut-off points which divide the mean area of the distribution, representing normal behaviour of the variable, from the left and right tail areas of the distribution, representing abnormal behaviour of the variable. The probability functions of the centre range and the tail areas are treated separately. The estimation on the tail part which contains extreme events is, therefore, not biased towards the centre and does not suffer from any pre-specified assumptions. Then, to see whether an economic variable issues a credible signal for currency instability, we test for asymptotic dependence, i.e. the strongest form of dependence, between extremes in the Thai baht market and economic indicators.

According to Pozo and Amuedo-Dorantes (2003), identifying currency crises using EVT is a good alternative to the conventional method. Based on the currency crisis definition provided by Eichengreen, Rose and Wyplosz (1996a), using the extreme value method to identify crises appears to track actual crisis events more closely than the conventional standard deviation approach since it signals more episodes of speculative pressure and indicates actual crisis incidences more accurately. By applying EVT to assess the tail dependence between currency crises measures and economic indicators, Cumperayot and Kouwenberg (2013) also show that the indicators selected by the extreme value method, using the concept of asymptotic dependence, perform better out-of-sample than the methods commonly used in other studies.

As we are interested in extreme events in the FX market and in the abnormal behaviour of economic variables that can potentially signal currency instability, EVT is a suited analytical tool. Without making prior assumptions about the shapes of unknown distributions, EVT provides a dependence measure that exclusively focuses on the tail area, in which the probability function and tail associations should technically be treated separately from the centre range. From the economic perspective, EVT facilitates our study of extreme dependence as we can assess the conditional probability of turmoil in the FX market for the given extreme quantiles of economic indicators, which is informative and relevant for the signalling approach that constitutes an early warning system for stress situations.

By focusing on the tail area, in this paper we identify potential economic indicators that may help signal the future instability of the Thai baht, captured by the exchange market pressure (EMP) index. We show that macroeconomic variables are highly non-normally distributed. Signals issued by most macroeconomic variables often used in other studies are moreover not reliable, as the variables are asymptotically independent of the currency

[1] The signalling approach developed by Kaminsky et al. (1998) relies heavily on the standard deviation method for identifying currency crises. Furthermore, the standard deviation method is also used to select "signal" thresholds for the fundamental economic indicators, minimising the noise-to-signal ratio.

instability measures. More importantly, we demonstrate how well the EVT-based signalling approach for currency instability can be applied to an individual country with a limited sample size. This is highly relevant for policy makers who are interested in a country's specific factors underlying currency instability.

Empirical studies of EVT often require a large sample size. To develop an early warning system for currency crises using low frequency macroeconomic data, it seems that pooling data from across countries is necessary. Although the panel analysis has certain pros, it may not account adequately for heterogeneity across countries. In this paper, we show that the EVT-based signalling approach can be implemented for an individual country with a small sample size, albeit with care required. The EVT tests provide results supported by non-parametric procedures which can be used as robustness checks. The non-parametric EVT approach itself also helps select economic indicators with high crisis prediction success as there is a strong link between the crisis prediction performance and the extremal association estimated.

II. CURRENCY INSTABILITY

In this paper, we select two measures to define the occurrence of extreme events in the Thai baht market.[2] The first measure is the rate of change of the exchange rate, i.e.

$$\Delta s_t = \ln s_t - \ln s_{t-1},$$

where s_t denotes a nominal spot exchange rate, quoted as a price of the US dollar in terms of Thai baht. This measure is used, for example, in the studies of Frankel and Rose (1996) and of Kumar, Moorthy and Perraudin (2003) to indicate currency crashes, represented by large swings in currency prices. A positive rate of change presented on the right tail of the distribution shows a large depreciation of the Thai baht, while a negative rate of change on the left tail represents a large appreciation of the Thai baht against the US dollar.

The second measure, which allows for a broader concept of currency instability, is from the works on currency crises by Eichengreen et al. (1996a, b). The exchange market pressure index, EMP_t, is defined as:

$$EMP_t = \mathbf{a}\,\Delta s_t + \mathbf{b}\,\Delta\tilde{i}_t - \mathbf{c}\,\Delta DINR_t\,,$$

where $\tilde{i}_t$ is the domestic-foreign (Thai-US) interest rate differential, $DINR_t$ is the differential between the Thai and US ratios of international reserves to broad money supply (M2). The weights **a**, **b** and **c** are attached to equalise the conditional volatility of each component. For example, given that $\sigma_{\Delta s}$, $\sigma_{\Delta\tilde{i}}$ and $\sigma_{\Delta DINR}$ are the standard deviations of Δs_t, $\Delta\tilde{i}_t$ and $\Delta DINR_t$, respectively, **a** is $\dfrac{1/\sigma_{\Delta s}}{1/\sigma_{\Delta s} + 1/\sigma_{\Delta\tilde{i}} + 1/\sigma_{\Delta DINR}}$.[3] In this paper, the standard deviations of Δs_t, $\Delta\tilde{i}_t$ and $\Delta DINR_t$ are equal to 0.0255, 0.0012 and 0.0698, respectively.

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[2] Our work has been inspired by the extensive body of literature on currency crises. See Flood and Marion (1999) and Sarno and Taylor (2002) for surveys of theoretical studies on currency crises. Surveys of the empirical literature on currency crises are found in Kaminsky et al. (1998) and Kumar et al. (2003).

[3] This "precision weight" technique is also discussed in Karimi and Voia (2015).

EMP_t does not only take into account large swings in the exchange rate, but also picks up other signs of pressure in the foreign exchange market. On the depreciation (appreciation) side, it provides a weighted average of the domestic currency depreciation (appreciation), a loss (gain) of international reserves, and a raise (decline) in the domestic interest rate under the variance-weighted scheme. The selling pressure on the Thai baht shows up as a large positive EMP_t on the right tail, while the buying speculative attacks would appear in the left tail of the distribution. For crisis signals, we use 21 economic variables from the currency crisis literature. These variables are from a consensus selection of successful indicators based on multiple works surveyed by Kaminsky et al. (1998).[4]

Research on currency crises mainly focuses on downward pressure on the domestic currency. This might be because in the downward pressure scenario, the limitations and time constraints on the authorities' side to defend the domestic currency is more pronounced, and in practice, the severe consequences of the collapse of the domestic currency are observed more regularly on the downward side. Nevertheless, experiences in China, Japan, Switzerland and many emerging market countries in the aftermath of the global financial crisis in 2008 have shown a vicious cycle of upward pressure that can disrupt the countries' economic performance.[5] In this paper, from the recent speculative capital inflows experience, we examine the factors which may drive the expected strengthening of the domestic currency and cause the upward pressure crisis.

The revaluation pressure on the Chinese Renminbi is caused by China's persistently large overall balance surplus, i.e. the surpluses in both its current account and non-central-bank financial account, rooted from the undervaluation of the currency. The expected revaluation of the Renminbi is further strengthened by the limitations imposed on authorities to defend its currency. The variables of interest on the trade side are increases in the trade balance, consisting of a rise in exports and a fall in imports, the terms of trade, and the undervaluation of the domestic currency. The implicit constraints on the authorities' ability to defend the exchange rate parity can be observed in rises in international reserves, money supplies, domestic credit, the money multiplier, inflation and the ratio of international reserves to imports.

Strong economic performance and overall balance surpluses are also factors that cause an expected appreciation of the domestic currency in other emerging market economies, as well as in Japan and Switzerland. However, there are also special features in these countries as well. For emerging market economies, like Brazil, Argentina and Thailand, relatively high yields are a main reason making such countries more attractive for global capital inflows. For Japan and Switzerland, a perception of a safe currency is a leading motive. This reputation comes from these countries' stable politics and economic performance resulting from their reliable institutional setup which is difficult to quantify. Adding to a set of variables described for the case of China, we examine increases and also decreases in the domestic price level and interest rates.

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[4] The Appendix provides details on the data source and construction for each indicator. The rationale for the selection of these indicators and the motivation for their expected signs are found in Kaminsky et al. (1998) and the Web Appendix. Kaminsky and Reinhart (1998, 1999) use these variables to reflect the macroeconomic background of the crises, such as financial liberalisation, current account, capital account and real sector. Kaminsky (2006) categorises the variables into 5 groups: first generation, second generation, third generation, sovereign debt and sudden stops. Qin and Liu (2014) use the real interest rate differential to reflect the market expectation as suggested by the second generation crisis models.

[5] See, for example, the effects of massive capital inflows ("capital bonanza") in the Economist (September 25th 2008) and Reinhart and Reinhart (2008).

III. EXTREME VALUE ANALYSIS

In this section, we explain how EVT can help address our research questions. First, by following univariate EVT, we discuss variables with heavy-tailed distributions and their implications. Then, through the bivariate extreme value analysis, we introduce multivariate EVT and describe how we investigate the extreme dependence structure between the measures of currency instability and the economic fundamentals.

III.1 The Univariate Case

Under some conditions, EVT provides a precise form of the asymptotic distribution of the extreme-value statistics of a random variable that is independent of its data generating process which is often unknown in practice.[6]

The limit distributions of the extreme-value statistics can be distinguished into three types depending on the shape parameter γ. If $\gamma < 0$, the extreme value distribution follows a Weibull-type distribution. The marginal distribution of the variable has a finite upper endpoint and therefore a short tail. When $\gamma = 0$, the extreme value distribution follows a Gumbel-type distribution and the marginal distribution has an exponentially decreasing tail function. If $\gamma > 0$, the extreme value distribution follows a Frechet-type distribution. Its marginal distribution has a polynomially decreasing tail function, i.e. a heavy-tailed distribution. The shape parameter γ is therefore crucial when one is interested in modelling tail behaviour.

According to the theory of heavy tails, a distribution function $F(x)$ is said to have heavy tails if its tails vary regularly (slowly) at infinity, i.e.

$$\lim_{t\to\infty}\frac{1-F(tx)}{1-F(t)} = x^{-\alpha}\ , x>0 \quad \text{and} \quad \alpha>0,$$ [7]

where α is a tail index and it is an inverse of the shape parameter γ. The marginal distribution $F(x)$ approaches infinity at a power rate and the number of existing unconditional moments is finite and equal to the integer value of α. A lower α (a higher γ) implies a slower rate of approaching infinity and thus higher accumulating probability (i.e. thicker) in the tail area. For instance, Pareto distributions satisfy the power law and have a number of bounded moments less than or equal to α. Normally distributed variables, on the other hand, follow the Gumbel extreme value distribution. Their distributions approach infinity at exponential rates, contain thin tails, and have an infinite number of existing unconditional moments.

Since variables with the Frechet distribution contain more probability mass in the tail areas than under the Gumbel distribution, assuming a normal distribution for the Frechet-distributed variable is likely to result in underestimating the probability of extreme events.

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[6] This is analogous to the central limit theorem which gives an asymptotic distribution for sample means. For details on univariate extremal analysis, the reader is referred to, e.g., Longin (1996) and Embrechts, Kluppelberg and Mikosch (1999).

[7] For the lower tail, $\lim_{t\to\infty}\frac{F(-tx)}{F(-t)} = x^{-\alpha}$, $x>0$ and $\alpha>0$.

Using EVT, we can estimate the shape parameter γ and test the hypothesis of heavy tails without imposing a specific parametric distribution. From the estimated shape parameter γ, we can also compare the tail fatness and the estimated number of existing unconditional moments. Furthermore, following de Haan, Jansen, Koedijk and de Vries (1994), we can empirically estimate the extreme probability-quantile which can be extended outside the historical sample range.

III.2 The Multivariate Case

To investigate the link between extreme movements in the Thai baht market and the economic fundamentals, we consider a pair of random variables: X and Y. Let us suppose that variable Y represents a measure of currency instability while X represents an economic fundamental. Extreme value statistics are then defined when X and Y are beyond the EVT thresholds θ_x and θ_y, respectively.[8]

According to Poon, Rockinger and Tawn (2004), the dependence structure between variables X and Y can be categorised into four types: independence, perfect dependence, asymptotic independence and asymptotic dependence. When a currency crisis measure and a fundamental variable are asymptotically independent, the conditional crisis probability approaches zero in the limit as the value of the economic indicator becomes more extreme. From a crisis prevention perspective, economic fundamentals that have some degree of regular dependence (non-zero correlation) with the currency crisis measures, but *no asymptotic dependence* in the tail area, are most likely poor indicators of currency crises as the relation between the variables vanishes for the extreme events that matter most.

In this paper, to see whether an economic variable issues a credible signal for instability in the Thai baht market, we test asymptotic dependence between the variables by considering the limit conditional probability $P\{Y > \theta_y | X > \theta_x\}$, i.e. the probability of Thai baht instability conditional on the abnormal behaviour (signal) of the economic variable X when both variables move more deeply into the tails and approach infinity.[9] Following the work of Poon et al. (2004), we next explain the concept of asymptotic dependence and its implications for our research objectives.[10]

The study of the multivariate distribution function $P\{Y > \theta_y ; X > \theta_x\}$ consists of two parts, which are the marginal distributions and the dependence structure. The former involves the univariate case discussed in the previous subsection. To study the dependence structure, the influence of the marginal distributions of X and Y, i.e. F_X and F_Y, is conventionally eliminated by transforming the raw data to a common marginal distribution, e.g., unit Frechet marginal distributions S and T, where

$$S = -1/\log F_X(X) \text{ and } T = -1/\log F_Y(Y).$$[11]

[8] For details on multivariate extreme value theory, the reader is referred to Peng (1999), Coles, Heffernan and Tawn (1999), Kotz and Nadarajah (2000), Longin and Solnik (2001), Hartmann, Straetmans and de Vries (2004), Poon et al. (2004), Beirlant, Goegebeur, Segers and Teugels (2004) and de Vries (2005).

[9] Without loss of generality, one can also consider minima, as results for one of the two can be immediately transferred.

[10] For other measures for extreme dependences, readers are referred to Beirlant et al. (2004). An alternative test for asymptotic dependence is also proposed in Peng (1999).

[11] Beirlant et al. (2004) discuss other choices of marginal distribution transformations and also state that the precise choice of transformation is not so important.

Now, S and T have the same distribution function, namely $F(z) = \exp(-1/z)$, and possess the same dependence structure as (X, Y). Thus, the transformation allows us to focus on differences in distributions that are purely due to dependence of extremes.

To identify the type of extremal dependence structure, we examine the limit conditional probability as in the research of Poon et al. (2004), who propose a pair of distribution-free dependence structure measures $(\chi, \bar{\chi})$ that can be non-parametrically estimated and statistically tested. Let $P(q)$ denote the probability of joint movements of variables S and T such that

$$P(q) = P\left[F(T) > q \middle| F(S) > q\right].$$

The conditional probability $P(q)$ measures the probability that $F(T) > q$ given that $F(S) > q$. At percentile *q*, if two events are independent, $P(q) = P[F(T) > q] = 1 - q$. If two events are positively dependent, $P(q) > 1 - q$, while $P(q) < 1 - q$ for negative dependence.

For extreme co-movements, we study asymptotic (in) dependence as variables approach their upper limits, i.e. when $q \to 1$. The function $P(q)$ measures the probability of variable T being close to its upper limit, as variable S reaches its upper limit. As $q \to 1$, the variables S and T are asymptotically independent if $P(q)$ has a limit equal to zero, while they are asymptotically dependent if in limit $P(q)$ is positive. Following on from this fact, the first nonparametric measure of dependence χ is defined as:

$$\chi = \lim_{q \to 1} P(q).$$

As variables S and T are on a common scale, we define *s* such that for both variables $F^{-1}(q) = s$ holds. Therefore,

$$\begin{aligned} \chi &= \lim_{s \to \infty} P(T > s \mid S > s) \\ &= \lim_{s \to \infty} \frac{P(T > s, S > s)}{P(S > s)}. \end{aligned}$$

The parameter χ measures the limit probability that extreme values of the variables S and T occur simultaneously.

If $\chi = 0$, S and T are asymptotically independent, i.e. the extreme values of the variables in limit occur independently. If $\chi > 0$, S and T are asymptotically dependent, while if $\chi = 1$, they are perfectly dependent. For variables that are asymptotically independent, Poon et al. (2004) measure their extreme dependence by using the second measure of extremal dependence $\bar{\chi}$, which is related to the rate at which $P(T > s \mid S > s)$ approaches 0,

$$\bar{\chi} = \lim_{s \to \infty} \frac{2 \log P(S > s)}{\log P(S > s, T > s)} - 1.$$ [12]

[12] See also Ledford and Tawn (1996) and Coles et al. (1999).

Note that $-1 \leq \bar{\chi} \leq +1$. If S and T are asymptotically dependent, $P(S > s, T > s)$ = $P(S > s)$ and $\bar{\chi}$ = 1. If S and T are independent, $P(S > s, T > s)$ = $[P(S > s)]^2$ and thus, $\bar{\chi}$ = 0. The positive and negative values of $\bar{\chi}$ correspond to positive and negative extreme association, respectively.

The associations between variables X and Y in the centre range and in the tail area do not need to be the same. Correlation measures often give little weight to tail events and, hence, they are proved to be inadequate in capturing the interdependency in the tail area. For example, Login and Solnik (2001); Embrechts, McNeill and Straumann (2002); Bradley and Taqqu (2003); Poon et al. (2004); and de Vries (2005) all show the discrepancy between the non-normally distributed variables and the normal based correlation measures. Boyer, Gibson and Loretan (1997) also point out the drawback of using conditional correlation coefficients to evaluate the extreme dependence even under normality. Embrechts et al. (2002) and de Vries (2005) demonstrate the case in which variables with zero correlation coefficient may exhibit extreme dependence. Hartmann et al. (2004) show the inaccurate estimation of joint extreme probabilities under the assumption of multivariate normality.

An advantage of using the approach of Poon et al. (2004) is that from the estimated parameters ($\bar{\chi}$, χ), we can simply measure the level of extremal dependence and estimate the conditional extreme event probability. The estimation mostly relies on only a few parameters but the results hold for a wide range of parametric distributions that are often unknown in practice. The results thus contain a crucial piece of information when constructing empirical distributions of multivariate extremes. Furthermore, these asymptotic results give a precise interpretation of genuine currency instability (infrequent extreme events) and abnormal economic behaviours, in which we are interested. These crisis incidents are suited to the specialised EVT techniques that focus exclusively on rare tail events.

IV. ESTIMATION

This section provides technical details regarding our estimation of the shape parameter γ (the inverse of the tail index α) and the EVT threshold we use to separate the tail area from the centre range. Also we explain how we identify the extremal dependence structure between variables using small size samples.

IV.1 Univariate Modeling of the Distribution Tails

To estimate the shape parameter γ, we apply the Hill (1975) estimator. In the case of heavy-tailed distributions, the Hill estimator has been shown to be asymptotically unbiased and more efficient than alternative estimators, as seen in, for example, Koedijk, Stork and de Vries (1992). Also the fact that the tail estimator follows an asymptotically normal distribution allows us to test for the amount of tail fatness and compare the tail fatness across distributions.[13] However, since the Hill estimator is only valid for the Frechet distribution, we use q-q plots to help justify the presumption that the underlying distributions are heavy tailed.

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[13] $(\hat{\gamma} - \gamma)m^{1/2}$ is asymptotically normal with mean zero and variance γ^2, see Jansen and de Vries (1991).

To estimate the Hill estimator, we define the ascending order statistics from a sample of size n as $X_{(1)} \le X_{(2)} \le ... \le X_{(n)}$. The nonparametric estimator proposed by Hill (1975) is

$$\hat{\gamma} = \frac{1}{m}\sum_{i=1}^{m}\left[\log X_{(n+1-i)} \big/ X_{(n-m)}\right],$$

where $\hat{\gamma}$ denotes the inverse tail index, i.e. $1/\hat{\alpha}$, and $X_{(n-m)}$ is a selected EVT threshold. Thus, there are m observations above the threshold.

One of the most essential steps in computing a tail index is to select the threshold, $X_{(n-m)}$, or the number of observations, m, included in the tail area. Too few observations can enlarge the variance of the estimate, while too many observations reduce the variance at the expense of biasedness due to including observations in the central range. There are several methods developed to deal with this trade-off problem. In this paper, we apply the simulation method proposed by Jansen and de Vries (1991) and also used by Poon et al. (2004).[14]

The estimated tail index $\hat{\alpha}$ is a measure of the amount of tail fatness of the distribution under investigation. The higher is $\hat{\gamma}$ (the lower is $\hat{\alpha}$), the thicker is the tail. The asymptotic normal distribution of the tail estimator allows us to test the significance of the tail fatness of random variables and to compare the tail fatness between two variables. Recalling that the inverse of the shape parameter γ is the tail index α, we note that the number of existing unconditional moments is finite and equal to the integer value of α. We can examine the tail fatness of the variables by testing $H_0 : \gamma \le z^{-1}$ $(H_0 : \alpha \ge z)$ against $H_1 : \gamma > z^{-1}$ $(H_1 : \alpha < z)$. The t-statistic computed for the tail of series *x* is

$$\mathrm{T}_x = \frac{\hat{\gamma}_x - z^{-1}}{\sigma(\hat{\gamma}_x)},$$

where z is the number of existing unconditional moments and $\sigma(\hat{\gamma}_x)$ is the asymptotic standard error.

As discussed earlier, the lower the number of existing unconditional moments, the thicker the tail. The tail function declines at a slower rate and, thus, the higher the frequency of abnormal movements, i.e. extreme pressure in the Thai baht market and signals issued by the economic variables. In this paper, we test $H_0 : \alpha \ge 10$. If the null hypothesis can be rejected, a single digit number of unconditional moments invalidates the assumption of normality that is often used in the literature. Instead, if the variables are thin tailed, the probability of extreme events declines rapidly as we move deeper into the tail area. The variables are less likely to behave irregularly, i.e. issue signals, which are supposed to be informative for the signalling approach that constitutes an early warning system.

[14] We also consider two additional methods for the tail index estimation developed for small samples. However, we find that the weighted average Hill estimator proposed by Huisman, Koedijk, Kool and Palm (2001) does not provide reasonable cut-off points in our sample. The recursive least squares implemented in Kalb, Kofman and Vorst (1996) and Pozo and Amuedo-Dorantes (2003) tends to give very high estimated γ and large number of observations in the tail *m*, compared to the simulation method. In some cases, the tail probability reaches 60% for the recursive least squares method.

IV.2 Multivariate Modelling of the Dependence Structure

The asymptotic dependence measures ($\overline{\chi}, \chi$), proposed by Poon et al. (2004) following on from Ledford and Tawn (1996, 1998), are ideal for the signalling approach. In this paper, after the unit Frechet data transformation, we test for asymptotic dependence between the currency instability measure and lagged economic variable (lags 1 to 12) by computing $\overline{\chi}$. If the estimated $\overline{\chi}$ is significantly less than 1, the variables are said to be asymptotically independent with $\chi = 0$. However, if the null hypothesis that $\overline{\chi} = 1$ cannot be rejected, the variables are asymptotically dependent. We then proceed to estimate χ, i.e. the limit probability that the extreme values of the variables occur simultaneously.[15] Without any specific parametric assumptions, we can investigate how the extreme dependence evolves through time.[16]

As a robustness check, we follow two additional procedures in cases where asymptotic dependence has been identified at the 5% significance level. Firstly, we test the relevancy of economic signals by comparing the unconditional probability of currency instability with the conditional probability given economic signals. If the signals are relevant, the conditional probability should be significantly higher than the unconditional probability. Secondly, we show the plot of the conditional probability, i.e. $P(q) = P(\, Y > F_Y^{-1}(q) \mid X > F_X^{-1}(q)\,)$, as both variables become more extreme. If the variables are asymptotically independent, the conditional probability rapidly goes to zero as $q \rightarrow 1$. However, for asymptotic dependent variables, the conditional probability approaches a constant number in the limit.

V. EMPIRICAL RESULTS

In this section, we investigate the fat tail feature and the linkage in the tails of two measures of currency instability and 21 economic indicators using monthly observations from the IMF's International Financial Statistics (IFS) from January 1974 to April 2011 (depending on data availability).[17] First, we examine the fat tail characteristics of each variable. Then, we test the usefulness of the economic variables as signals for turmoil in the Thai baht market.

V.1 Preliminary Evidence of Heavy Tails

To provide evidence regarding the non-normality of the distributions of the variables used in this paper, we show q-q plots in this subsection.[18] Figure 1 presents the q-q plot of each variable against a normal distribution using the variable's sample mean and standard deviation. To give an idea of the tail fatness of the variables, in Figure 2 we plot the sample

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[15] Poon et al. (2004) provide a non-parametric method to estimate and test for asymptotic dependence using a pair of distribution-free dependence structure measures ($\overline{\chi}, \chi$).

[16] Rather than estimating the probability of turmoil in the FX market within the next 24-month window as in Kaminsky et al. (1998), we show the time structure of extreme dependence.

[17] The Appendix contains details of the data, time series construction and descriptive statistics of the variables used in the paper. The out-of-sample period is from May 2011 to July 2013.

[18] According to the Jarque-Bera normality test and the augmented Dickey-Fuller unit root test, the null hypothesis of a normal population distribution and the null hypothesis of a unit root can be rejected at a 5% significance level for all the variables. To save space, we do not display the results. Test results are available upon request.

quantiles of each variable against the quantiles from a Student-t distribution with the sample mean (mu), standard deviation (sigma) and the degrees of freedom (ν) illustrated on the *y*-axis. The degrees of freedom from a Student-t distribution indicate the variable's tail fatness and the number of bounded moments.

In Figure 1, the sample quantiles on the horizon axis are plotted against the respective normal quantiles on the vertical axis. If a variable of our interest is normally distributed, the plot would follow a straight line. Instead, in most cases we observe that the q-q plots are arced or have an *S* shape. There are however exceptions in the case of imports (IM) in which the plot is pretty much linear, and to a lesser extent for the cases of exports (EX) and the international reserves to imports ratio (IRIM) in which deviations from the linear line appear only on both ends. For the real interest rate (RI) and the deviation of the real exchange rate from its time trend (QD1 and QD2), the lines are almost linear, with small deviations on both ends.

Figure 1 points towards the fact that most variables are more skewed or have heavier tails than the normal distribution with the same mean and standard deviation. The *S* shape is clearly observed in the case of the nominal and real exchange rate returns (S and QC). An *S*-shaped q-q plot indicates a leptokurtic distribution, i.e. a distribution with a higher and narrower peak and fatter tails than a normal distribution. The heavier the tails of the exchange rate returns, the higher the probability of large swings. For the exchange market pressure index (EMP), the plot is also skewed to the right. A long right tail (and thus a short left tail) implies a higher probability of a downward market pressure than an upward market pressure.

To further investigate the non-normality of the distributions, in Figure 2 we examine whether the variables follow a student-t distribution. This is due to the fact that the Student-t distribution has heavy tails and a number of existing moments which is equal to the integer of its degrees of freedom. The lower the degrees of freedom, i.e. the lower the tail index α, the fatter the tails of the distribution, which implies the higher the probability of extreme events. The plot and the estimated degrees of freedom (ν) on the *y*-axis give a preliminary idea about the tail fatness of the variables. In the next subsection, we directly estimate and test the tail thickness using EVT and treat the left and right tails separately.

Figure 2 demonstrates that, in most cases, the q-q plots closely follow linear lines. The better fit, which is rather obvious compared to Figure 1, suggests that the behaviour of these variables is more likely to resemble the Student-t than the normal distribution. Except for imports (IM), the deviation of the real exchange rate from its time trend (QD1 and QD2) and the international reserves to imports ratio (IRIM), the estimated degrees of freedom are in single digits. Among those, only exports (EX), the real interest rate (RI) and the deviation of the real exchange rate from the moving average process (QD3) have estimated degrees of freedom higher than 5. The lower the degrees of freedom, the heavier the tails.

The evidence confirms that in almost all cases, the probability of large movements of the variable is higher than the normal benchmark. Fitting the normal distribution will underestimate the likelihood of turmoil in the FX market and economic signals, apart from ignoring the asymmetric property of the distributions in some cases. The Student-t distribution outperforms the normal distribution in describing the behaviour of most variables, especially in the centre range. Nevertheless, excluding imports (IM) and the international reserves to imports ratio (IRIM), there are still dispersions on both ends after fitting the Student-t distribution. To yield better understanding of the extreme behaviour, in the next subsection we consider left and right tails separately using EVT.

V.2 Tail Index and Threshold Estimates

In this subsection, we report the Hill (1975) estimates and their associated EVT thresholds based on the simulation method proposed by Jansen and de Vries (1991). Table 1 shows the Hill estimates, $\hat{\gamma}$, and standard deviations (in parenthesis) for the left (-) and right (+) tails of each variable in the third column. The fourth column displays the estimated tail index $\hat{\alpha}$ ($=1/\hat{\gamma}$) with asterisks indicating whether the tail index is significantly less than 10.[19] In the last two columns, for each tail of each variable, we demonstrate the probability of extreme events and the associated EVT threshold that separates observations in the centre range from the extreme observations which represent currency instability and economic signals.

While the right (left) tail of the currency measures (S and EMP) indicates the downward (upward) pressure in the Thai baht market, for most economic indicators, the right (left) tail generally shows dramatic increases (decreases) in the variables. However, for the real interest rate (RI) and the real interest rate differential (RID), the right (left) tail contains abnormally large positive (negative) rates of interest. High undervaluation (overvaluation) of the Thai baht is in the right (left) tail of the deviation of the real exchange rate (QD1, QD2 and QD3). Furthermore, as previously stated, the tail index α is a measure of the amount of tail fatness and the number of existing moments of the distribution under investigation. The higher $\hat{\gamma}$ is (the lower $\hat{\alpha}$ is), the thicker the tail will be.

In Table 1, there are only two cases in which we cannot reject the null hypothesis in favour of the alternative hypothesis of the single-digit tail index at a 10% significance level. Those cases are the positive growth rate of monthly exports (EX) and the overvaluation of the Thai baht measured by QD3. However, in 38 out of 46 estimates (around 82.6%), the null hypothesis can be rejected at a 1% significance level. The point estimates show that all variables have tail indices of less than 4, except for both tails of imports (IM) and the currency misalignment measures (QD1, QD2 and QD3); the right tail of exports (EX), the real interest rate (RI) and the real interest rate differential (RID); and the left tail of the international reserves to imports (IRIM).

The exchange rate returns (S), the domestic interest rate change (I), the interest rate differential change (ID), and trade balance growth (TB) have at least one of the estimated tail indices below 1, which means that the first moment (unconditional mean) may not exist. For a large group of the variables, the integral of the mean may be bounded, but the existence of the second moment (unconditional variance) is debatable. These variables are the exchange market pressure index (EMP), inflation (INF), inflation differential (INFD), domestic real interest rate (RI), real interest rate differential (RID), real exchange rate (QC), and monthly changes in money supply (MS), terms of trade (TT), money multiplier (MM), domestic credit (DC), real commercial bank deposit (BD), and the ratio of money supply to international reserves (MIR).

The lower the estimated tail index, it can be implied that the fatter the tail will be and thus the higher the probability in the tail area. From the fifth column, the probability in the tail area when the estimated tail index is less than 1 ranges from 22.37% to 39.91%, while the tail probability is between 2.24% and 6.19% for the case in which the estimated tail index is above 4. The last column illustrates the EVT thresholds we used to separate observations in the centre range from observations in the tail area. For the currency instability measures (S and EMP), the extreme downward pressure is said to occur when the variable moves beyond its threshold on the right tail, whereas the extreme upward pressure in the Thai baht market is identified when the variable is below the threshold on the left tail.

[19] Throughout the paper, an asterisk indicates significance at a 10% level, while two and three asterisks show significance at 5% and 1% levels, respectively.

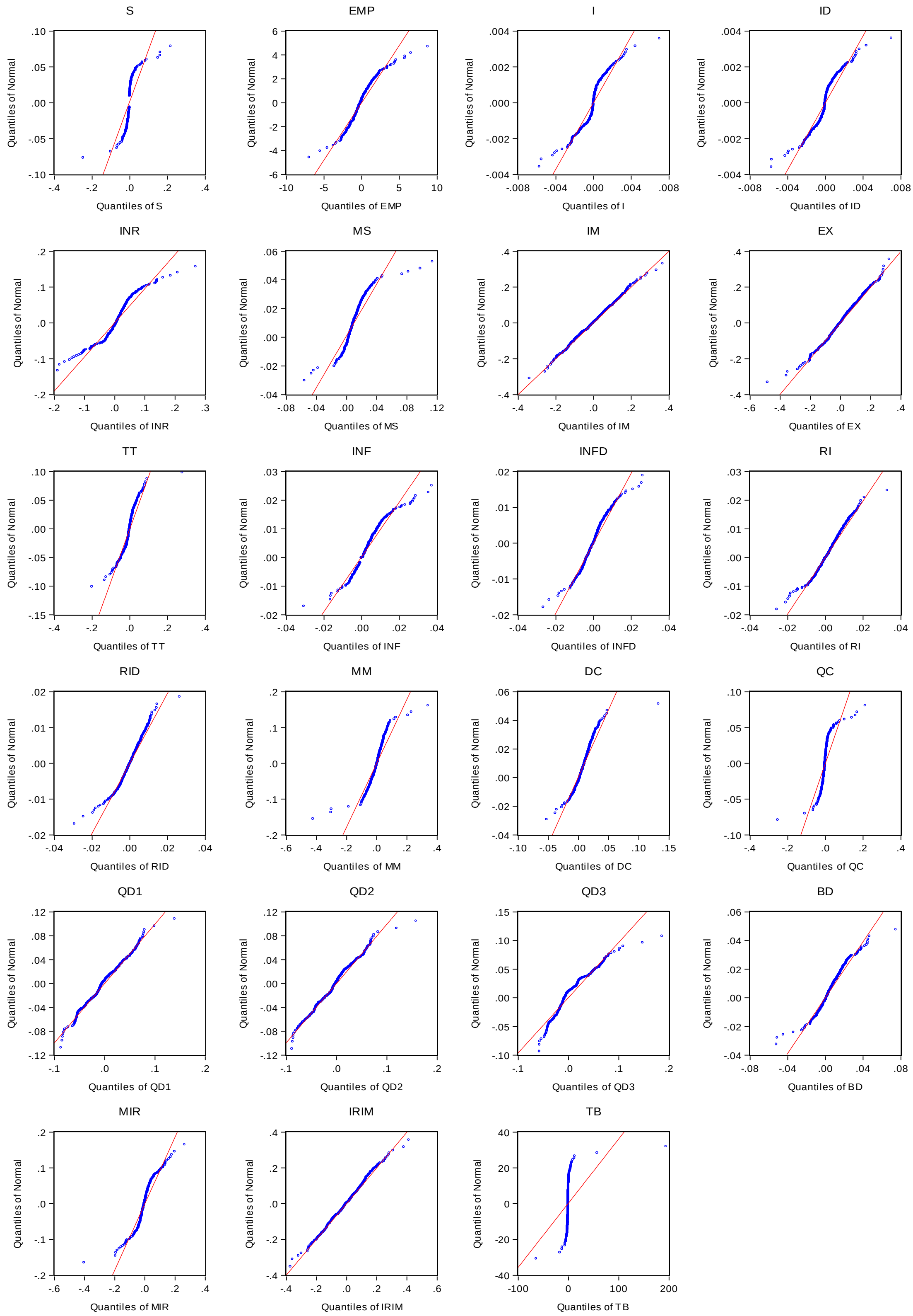

Fig. 1. Normal q-q plots.

Note: In each normal q-q plot, the sample quantiles on the horizon axis are plotted against the respective normal quantiles on the vertical axis, using the variable's sample mean and standard deviation.

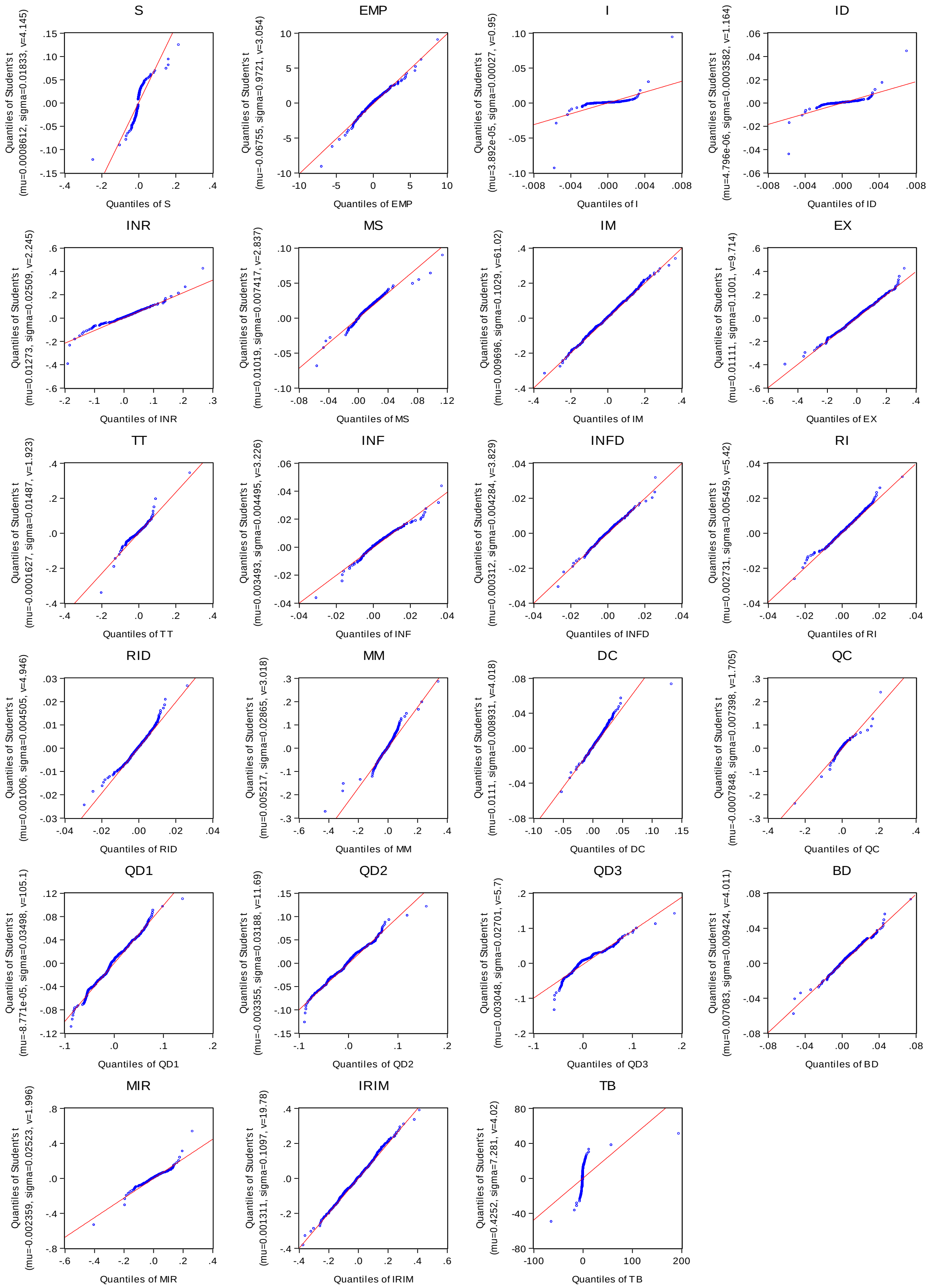

Fig. 2. Student-t q-q plots.

Note: The sample quantiles of each variable are plotted against the quantiles from a Student-t distribution with the sample mean (mu), standard deviation (sigma) and the degrees of freedom (ν) illustrated on the *y*-axis.

TABLE 1

Tail Index Estimates and Thresholds

Variables	**Left tail (-)/ Right tail (+)**	**Est. Hill ($\hat{\gamma} = 1/\hat{\alpha}$) Jansen & de Vries (standard deviation)**	$\hat{\alpha}$ **(Ho: α ≥ 10)**	**Probability in the tail**	**EVT Threshold**
Spot exchange rate (USD-THB) (S)	-	1.3956 (0.1210)	0.7165***	29.75	-0.236%
	+	1.1901 (0.1190)	0.8402***	22.37	0.391%
Exchange Market Pressure index (EMP)	-	0.3946 (0.0667)	2.5342***	8.52	-1.6083
	+	0.5206 (0.0776)	1.9209***	10.95	1.5954
Domestic nominal interest rate (I)	-	0.5254 (0.0783)	1.9033***	10.95	-1.464%
	+	1.2653 (0.1127)	0.7903***	30.66	0.252%
Nominal interest rate differential (ID)	-	0.4106 (0.0694)	2.4355***	8.52	-1.752%
	+	1.3679 (0.1219)	0.7310***	30.66	0.24%
International reserves (INR)	-	0.2548 (0.0681)	3.9246**	3.13	-9.878%
	+	0.4669 (0.0674)	2.1418***	10.74	5.270%
Domestic money supply (MS)	-	0.6507 (0.2058)	1.5368***	2.24	-1.160%
	+	0.3552 (0.0628)	2.8153***	7.16	2.620%
Imports (IM)	-	0.2499 (0.0521)	4.0016***	5.16	-15.545%
	+	0.2212 (0.0507)	4.5208***	4.26	18.302%
Exports (EX)	-	0.3407 (0.0602)	2.9351***	7.17	-14.861%
	+	0.0933 (0.0295)	10.7181	2.24	25.439%
Terms of trade (TT)	-	0.4239 (0.0679)	2.3590***	8.88	-4.020%
	+	0.6631 (0.0810)	1.5081***	15.26	1.910%
Inflation (INF)	-	0.5058 (0.0894)	1.9771***	7.16	-1.326%
	+	0.3983 (0.0638)	2.5107***	8.72	3.537%
Inflation differential (INFD)	-	0.4774 (0.0689)	2.0947***	10.74	-1.647%
	+	0.4105 (0.0657)	2.4361***	8.72	2.343%
Domestic real interest rate (RI)	-	0.6807 (0.0864)	1.4691***	15.05	-4.26%
	+	0.2414 (0.0493)	4.1425***	5.83	15%
Real interest rate differential (RID)	-	0.5685 (0.0848)	1.7590***	10.92	-6.12%
	+	0.2079 (0.0490)	4.8100**	4.37	11.7%

TABLE 1 (CONTINUED)

Tail Index Estimates and Thresholds

Variables	**Left tail (-)/ Right tail (+)**	**Est. Hill ($\hat{\gamma} = 1/\hat{\alpha}$) Jansen & de Vries (standard deviation)**	$\hat{\alpha}$ **(Ho: α ≥ 10)**	**Probability in the tail**	**EVT Threshold**
M2 multiplier (MM)	-	0.4845 (0.0699)	2.0640***	10.76	-4.435%
	+	0.4026 (0.0645)	2.4839***	8.74	4.966%
Domestic credit (DC)	-	0.5145 (0.1375)	1.9436***	3.14	-1.252%
	+	0.2671 (0.0557)	3.7439***	5.16	2.828%
Real exchange rate (QC)	- Appreciation	0.6556 (0.0801)	1.5253***	15.02	-1.10%
	+ Depreciation	0.9130 (0.0913)	1.0953***	22.42	0.648%
Currency misalignment (QD1)	- overvaluation	0.1952 (0.0448)	5.1230**	4.25	-5.587%
	+ undervaluation	0.1538 (0.0385)	6.5020*	3.58	6.598%
Currency misalignment (QD2)	- overvaluation	0.1868 (0.0429)	5.3533**	4.27	-6.269%
	+ undervaluation	0.1914 (0.0439)	5.2247**	4.27	6.044%
Currency misalignment (QD3)	- overvaluation	0.1277 (0.0354)	7.8309	3.35	-4.138%
	+ undervaluation	0.2435 (0.0497)	4.1068***	6.19	6.500%
Real commercial bank deposit (BD)	-	0.6343 (0.1016)	1.5765***	8.74	-0.740%
	+	0.3421 (0.0605)	2.9231***	7.17	2.399%
M2 (US$) to international reserves (MIR)	-	0.6731 (0.0822)	1.4857***	15.02	-3.308%
	+	0.6987 (0.0854)	1.4312***	15.02	3.437%
International reserves to imports (IRIM)	-	0.2429 (0.0507)	4.1169***	5.16	-18.491%
	+	0.3144 (0.0556)	3.1807***	7.17	15.741%
Trade balance (TB)	-	0.9977 (0.0998)	1.0023***	22.42	-48.109%
	+	1.9701 (0.1477)	0.5076***	39.91	9.053%

Note: For the left (-) and right (+) tails of each variable, this table shows the Hill estimate, $\hat{\gamma}$, and standard deviation (in parenthesis) in the third column, while the fourth column displays the estimated tail index $\hat{\alpha}$ $(=1/\hat{\gamma})$ with asterisks indicating whether the tail index is significantly less than 10. The fifth and sixth columns show the probability of extreme events and the associated EVT threshold, respectively. An asterisk indicates significance at a 10% level, while two and three asterisks show significance at 5% and 1% levels, respectively. In the last column, most variables are monthly rates of change and monthly changes for the nominal interest rate variables. For EMP, the variable is the exchange rate market pressure index measured at month *t*. For the deviation of the real exchange rate (QD), real interest rate (RI), and real interest rate differential (RID), the variables are measured in percentage at month *t*.

For the exchange rate returns (S), the probabilities of the extreme downward and upward pressure are 22.37% and 29.75%, respectively. The EVT thresholds for the large depreciation and the large appreciation of the Thai baht relative to the US dollar are equal to 0.391% and -0.236% monthly (4.692% and -2.832% annually), respectively. The EVT thresholds for the exchange rate returns are rather conservative because the sample period in our study has been dominated by the time when the Thai baht was de facto pegged against the US dollar (from February 1974 to June 1997: 62.86% of the observations). Furthermore, the Thai baht was under a hard peg with occasional changes in the exchange rate from February 1974 to October 1984, accounting for 28.86% of the whole sample.

The experience of the de facto pegged Thai baht that was followed by the collapse of the currency in July 1997 results in a highly leptokurtic distribution. During the period of the hard peg alone, the probabilities of large downward and upward swings of the Thai baht are only 2.33% and 0.78%, respectively. For the entire period of the de facto pegged exchange rate regime, the probabilities of the extreme events rise to 14.23%% and 18.51%, respectively. However, under the managed floating exchange rate regime (January 1998 to April 2011) changes in the exchange rate outside the range of these conservative thresholds become much more common, with the probabilities equal to 34.38% and 50.63%, respectively.[20]

Nevertheless, due to the low frequency of macroeconomic data used as signalling indicators, we are obliged to use coarse exchange rate returns and pool the data across exchange rate regimes in order to have sufficient observations. For flexible exchange rate regimes recently used in Thailand, the usefulness of the exchange rate returns to identify extreme events in the Thai baht market may thus seem doubtful. Yet, we have the EMP index which gives more robust results across the exchange rate regimes. Based on the EMP index, the probabilities of extreme downward and upward pressure in the Thai baht market are 10.95% and 8.52%, respectively. An extreme downward pressure is said to occur when EMP is higher than 1.5954, whereas an extreme upward pressure is identified when EMP is below -1.6083.

From February 1977 to October 1984, when the Thai baht was firmly pegged against the US dollar, the probabilities of the downward and upward market pressure are 17.58% and 6.59%, respectively. For the entire period of the de facto pegged exchange rate regime (from February 1977 to June 1997), the probabilities are equal to 14.69% and 10.20%. Under the managed floating exchange rate regime, the probabilities of speculative attacks with selling and buying pressure on Thai baht fall to 2.50% and 5.63%. In our view, the EMP index provides more intuitive results: the likelihood of extremes in the FX market tends to be higher for less flexible exchange rate regimes and the Thai baht has relatively been under more buying pressure than selling pressure since the recovery from the Asian crisis in 1997.

However, there are at least two criticisms regarding the use of the EMP index. First, the EMP index may fail to capture policy strategies in the face of speculative attacks. As pointed out in Li, Rajan and Willett (2006), a country which prefers to defend its currency by directly intervening in the foreign exchange market, as Thailand did, may have highly volatile international reserves. This intervention results in a low weight on its international reserves, which may pull back the EMP index from reaching extreme values and reflecting speculative pressure on its domestic currency. Second, the weight for each component of the EMP may be different for different exchange rate regimes. Following the different exchange rate policies before and after the Asian crisis in July 1997, we therefore construct another EMP index using different weights for these two periods of different exchange rate policies.

[20] The de facto exchange rate regime classification is from Ilzetzki, Reinhart and Rogoff (2008).

For the fixed exchange rate regimes (February 1974 to June 1997), the standard deviations of the EMP components Δs_t, $\Delta \tilde{i}_t$ and $\Delta DINR_t$ are 0.0123, 0.0013 and 0.0740, respectively. In the period of floating exchange rate regimes (July 1997 to April 2011), the standard deviations are 0.0387, 0.0010 and 0.0614. The standard deviation of exchange rate returns appears to be higher during the floating exchange rate regime, while the standard deviations of tools used to defend the currency value, such as changes in short-term interest rates and international reserves, remain similar. Both the old and new EMP series are highly correlated with the correlation coefficient of 0.9230. In the tails, they have similar estimated tail indices and thresholds.[21]

As the EMP index takes into account pressure in the foreign exchange market that does not necessarily result in swings in currency prices, it is more robust in defining the extreme FX market pressure across exchange rate regimes than coarse exchange rate returns. The series itself is also not affected by different component weights across regimes. In this paper, we thus report the empirical results for the EMP series using the fixed component weights for the entire sample.[22] Once we consider the out-of-sample period (May 2011 to July 2013), the EMP index does not indicate any extreme episode. This is due to the relatively smooth movements of the exchange rate, interest rate and international reserves under the current managed floating exchange rate regime.[23]

V.3 Tail Dependence of EMP Index and Lagged Economic Fundamentals

To see whether an economic variable issues a credible signal for extreme FX market turmoil, we statistically test asymptotic dependence between the EMP index and 12 lags of economic indicators after the unit Frechet data transformation. Table 2 displays the test results for the downward and upward FX market pressure, separately. For each EMP index and lagged economic indicator pairing, we report the highest estimated tail dependence $\hat{\bar{\chi}}$ among the estimates from lag 1 to lag 12 (with variance in parentheses). The next columns show the lag with the highest $\hat{\bar{\chi}}$ and the limit conditional probability $\hat{\chi}$, estimated for the variables which cannot reject the null hypothesis of asymptotic dependence.

Most pairings of a lagged economic fundamental and the EMP index can reject the null hypothesis of asymptotic dependence, i.e. $\bar{\chi} = 1$, at a 1% significance level. These pairs of

[21]

Variable	Left tail (-)/ Right tail (+)	Est. Hill ($\hat{\gamma} = 1/\hat{\alpha}$) Jansen & de Vries (standard deviation)	$\hat{\alpha}$ (Ho: α ≥ 10)	Probability in the tail	EVT Threshold
EMP using different weights before and after the Asian crisis	-	0.3398 (0.0610)	2.9429***	7.54	-1.6272
	+	0.5331 (0.0795)	1.8758***	10.95	1.5315

[22] Parallel studies have also been conducted of exchange rate returns and the EMP index with different component weights for different regimes. Both EMP series yield the same conclusions regarding 1) their asymptotic dependence with economic indicators and 2) their out of sample crisis prediction. Results are available upon request.

[23] Recall that the standard deviations of the EMP components Δs_t, $\Delta \tilde{i}_t$ and $\Delta DINR_t$ for the entire period are 0.0255, 0.0012 and 0.0698, respectively. For the floating exchange rate regimes alone (July 1997 to April 2011), the standard deviations are 0.0387, 0.0010 and 0.0614. If we exclude the Asian crisis episode (July to December 1997) we have the non-crisis episode of floating exchange rate regimes with the standard deviations are 0.0314, 0.0006 and 0.0560. However, for the out of sample period (May 2011 to July 2013) the standard deviations largely decline to 0.0192, 0.0001 and 0.0188, respectively.

variables are asymptotically independent with $\chi = 0$. However, for the extreme downward pressure on the right tail of EMP, we cannot reject the null hypothesis for a decline in the international reserves (INR) at a 10% significance level, for an increase in the ratio of money supply to international reserves (MIR) at a 5% significance level, and for the overvaluation of the Thai baht (QD1) at a 1% significance level. For the upward FX market pressure on the left tail of EMP, at a 5% significance level, the variable is a large increase in the interest rate differential (ID), while at a 1% significance level, the variables are surges in the nominal interest rate (I), drops in the nominal interest rate (I) and the interest rate differential (ID), the real depreciation of the Thai baht (QC), and the undervaluation of the Thai baht (QD3).

In Table 3, we show the estimated extremal dependence measures ($\bar{\chi}$, χ) for lag 1 to lag 12 for the EMP index and the economic indicator pairings that fail to reject the null hypothesis of asymptotic dependence at a 5% significance level in Table 2. For the lags at which the estimated $\bar{\chi}$ cannot reject the null hypothesis at a 5% significance level, we also estimate χ: the limit probability of turmoil in the Thai baht market given an economic signal. For $\bar{\chi}$, the t-statistics in parentheses are from the null hypothesis that $\bar{\chi} = 1$, while for χ the null hypothesis is $\chi = 0$. Tables 2 and 3 illustrate that the case of asymptotic dependence is rather rare in our sample. However, when the EMP index and lagged economic variables are asymptotically dependent, it implies that their relations in the tails do not vanish as both variables approach infinity and their behaviour becomes more extreme. Therefore, these variables provide reliable signals.

From Table 3, the monthly growth rates of the international reserves (INR, -) and the ratio of money supply to international reserves (MIR, +) give significant signals only one month before the extreme downward pressure in the Thai baht market, with a limit probability of around 0.4. For the extreme buying pressure, the only variable that is asymptotically dependent with the EMP index at a 5% significance level is an increase in the interest rate differential (ID, +). The limit probability is roughly 0.3. It is noteworthy that most economic variables are asymptotically independent of the EMP index. Hence, as these economic variables become more extreme, the likelihood of more extreme events in the Thai baht market counter-intuitively declines. These variables are, therefore, poor indicators of currency instability. Their signals are less credible, as they move deeper into the tails.[24]

V.4 Robustness Checks

Our small sample size (411 to 446 observations) may reduce the test power in rejecting the null hypothesis of asymptotic dependence. In this subsection, we thus follow two additional non-parametric procedures to determine whether the economic variables which are asymptotically associated with the EMP index can help provide relevant economic signals for extreme events in the Thai baht market. For the lagged economic indicators which cannot reject the null hypothesis of asymptotic dependence with the EMP index at a 5% significance level, we first compare the unconditional and conditional probabilities of the EMP's extreme events given signals issued by the economic indicators, using the lag which yields the highest conditional probability. Second, we graphically inspect the limit conditional probability.

[24] As recommended by an anonymous referee, we have re-estimated Tables 2 and 3 using the real exchange market pressure index ($REMP_t$), which is the EMP index adjusted for inflation. Our conclusion remains the same: Most economic indicators are asymptotically independent with the REMP index. Only the international reserves and the ratio of money supply to international reserves give significant signals at lag two.

Using the EVT thresholds, we transform the series of the EMP index and the economic variables into binary indicators. Observations in the tail area are set equal to 1, and 0 otherwise. Then, we test for the tail independence of the EMP index and economic signals using a chi-squared test for a 2 by 2 contingency table (cross-tab). If extreme events of the EMP and the lagged economic indicator are associated, i.e. the signals are relevant, the conditional probability of the EMP's extreme events should be significantly higher than the unconditional probability. The larger the conditional probability, the more informative the economic signal. Table 4 reports the unconditional probability (Uncon. Prob), the conditional probability (Con. Prob) and Pearson's chi-squared test statistic with *p*-value in parentheses.

TABLE 2

Asymptotic Dependence between the EMP index and Lagged Economic Signals

Variable	**Left tail (-)/ Right tail (+)**	**Downward Pressure in the Thai Baht market**		
		EMP		
		$\hat{\bar{\chi}}$ (variance)	**Lag**	**Limit Con. Prob**
International reserves (INR)	-	0.821 (0.0400)	1	0.401
Domestic money supply (MS)	+	0.498*** (0.0299)	1	
Imports (IM)	+	0.363*** (0.0281)	12	
Exports (EX)	-	0.398*** (0.0296)	9	
Terms of trade (TT)	-	0.438*** (0.0313)	2	
Inflation (INF)	+	0.449*** (0.0318)	6	
Inflation differential (INFD)	+	0.544*** (0.0318)	4	
Real interest rate (RI)	+	0.386*** (0.0291)	2	
Real interest rate differential (RID)	+	0.424*** (0.0307)	2	
M2 multiplier (MM)	+	0.417*** (0.0304)	7	
Domestic credit (DC)	+	0.536*** (0.0315)	2	
Real exchange rate (QC)	- (appreciation)	0.222*** (0.0271)	8	
Currency misalignment (QD1)	- (overvaluation)	0.661** (0.0368)	12	0.360
Currency misalignment (QD2)	- (overvaluation)	0.169*** (0.0248)	12	
Currency misalignment (QD3)	- (overvaluation)	0.017*** (0.0220)	10	
Real commercial bank deposit (BD)	-	0.275*** (0.0296)	8	
M2 (US$) to international reserves (MIR)	+	0.742* (0.0366)	1	0.411
International reserves to imports (IRIM)	-	0.410*** (0.0301)	3	
Trade balance (TB)	-	-0.031*** (0.0200)	10	

TABLE 2 (CONTINUED)

Asymptotic Dependence between the EMP index and Lagged Economic Signals

Variable	**Left tail (-)/ Right tail (+)**	**Upward Pressure in the Thai Baht market**		
		EMP		
		$\hat{\chi}$ (variance)	**Lag**	**Limit Con. Prob**
Domestic nominal interest rate (I)	+	0.630** (0.0354)	7	0.339
	-	0.664** (0.0369)	12	0.335
Nominal interest rate differential (ID)	+	0.729* (0.0398)	10	0.310
	-	0.601** (0.0342)	12	0.348
International reserves (INR)	+	0.573*** (0.0330)	6	
Domestic money supply (MS)	+	0.418*** (0.0305)	7	
Imports (IM)	-	0.532*** (0.0356)	1	
Exports (EX)	+	0.360*** (0.0280)	7	
Terms of trade (TT)	+	0.378*** (0.0288)	11	
Inflation (INF)	+	0.312*** (0.0313)	1	
	-	0.305*** (0.0309)	7	
Inflation differential (INFD)	+	0.453*** (0.0320)	5	
	-	0.281*** (0.0298)	11	
Real interest rate (RI)	+	0.427*** (0.0309)	8	
Real interest rate differential (RID)	+	0.519*** (0.0350)	3	
M2 multiplier (MM)	+	0.380*** (0.0289)	10	
Domestic credit (DC)	+	0.560*** (0.0325)	9	
Real exchange rate (QC)	+ (depreciation)	0.629** (0.0354)	7	0.343
Currency misalignment (QD1)	+ (undervaluation)	0.321*** (0.0264)	2	
Currency misalignment (QD2)	+ (undervaluation)	0.534*** (0.0356)	2	
Currency misalignment (QD3)	+ (undervaluation)	0.678** (0.0376)	5	0.332
International reserves to imports (IRIM)	+	0.470*** (0.0327)	6	
Trade balance (TB)	+	0.216*** (0.0269)	9	

Note: This table reports the highest estimated tail dependence $\hat{\chi}$ among lag 1 to 12 (with its variance in parentheses), the associated lag, and the limit conditional probability for the variables which cannot reject the null hypothesis of asymptotic dependence. We test $H_0 : \bar{\chi} \geq 1$, versus $H_1 : \bar{\chi} < 1$. An asterisk indicates significance at a 10% level, while two and three asterisks show significance at 5% and 1% levels, respectively.

TABLE 3
Asymptotic Dependence Structure of the EMP index and Economic Signals

Currency Measures	Economic Indicators		Lag											
			1	2	3	4	5	6	7	8	9	10	11	12
EMP(+)	INR(-)	$\hat{\bar{\chi}}$	0.821 (-0.895)	0.530*** (-2.660)	0.567*** (-2.394)	0.483*** (-3.015)	0.381*** (-3.641)	0.238*** (-4.560)	0.373*** (-3.709)	0.414*** (-3.365)	0.340*** (-4.002)	0.313*** (-3.878)	0.205*** (-4.893)	0.102*** (-5.582)
		$\hat{\chi}$	0.401*** (10.198)											
	MIR(+)	$\hat{\bar{\chi}}$	0.742* (-1.351)	0.541*** (-2.583)	0.657** (-1.790)	0.438*** (-3.176)	0.236*** (-4.581)	0.220*** (-4.746)	0.305*** (-4.325)	0.509*** (-2.819)	0.339*** (-4.010)	0.290*** (-4.084)	0.479*** (-2.865)	0.116*** (-5.880)
		$\hat{\chi}$	0.411*** (10.198)											
EMP(-)	ID(+)	$\hat{\bar{\chi}}$	0.473*** (-3.101)	0.389*** (-3.573)	0.522*** (-2.721)	0.505*** (-2.849)	0.294*** (-4.429)	0.282*** (-4.549)	0.699* (-1.532)	0.522*** (-2.551)	0.491*** (-2.774)	0.729* (-1.359)	0.441*** (-3.148)	0.568*** (-2.389)
		$\hat{\chi}$							0.318*** (9.597)			0.310*** (9.605)		

Note: This table shows the estimated ($\bar{\chi}$, χ) at different lags for EMP index and economic indicator pairings for which there is at least one estimated $\bar{\chi}$ (from lags 1 to 12) which cannot reject the null hypothesis of asymptotic dependence at a 5% significance level. For the lags which the estimated $\bar{\chi}$ cannot reject the null hypothesis of asymptotic dependence at a 5% significance level, we also estimate χ . For $\bar{\chi}$, the t-statistics in parentheses are from the null hypothesis that $\bar{\chi} = 1$, while for χ , the null hypothesis is $\chi = 0$. An asterisk indicates significance at a 10% level, while two and three asterisks show significance at 5% and 1% levels, respectively. Positive and negative signs indicate the right and left tails of the variables, respectively.

For the extreme downward pressure captured by the right tail of EMP, positive changes in the ratio of money supply to international reserves (MIR, lag 1) as well as the negative growth rate of the international reserves (INR, lag 1) can reject the null hypothesis of independence at a 1% significance level.[25] For the upward pressure on the left tail of EMP, monthly increase in the interest rate differential (ID, lag 8) can also reject the null hypothesis of independence at a 1% significance level as well. For INR and MIR, lag 1 yields both the highest conditional probability as well as the highest $\hat{\bar{\chi}}$. Next, we further investigate the link in the tails between the EMP index and the lagged economic fundamentals by graphically examining the limit conditional probability.

Recalling that *Y* represents the EMP index and *X* represents a lagged economic fundamental, multivariate extremes are then defined when $X > \theta_x$ and $Y > \theta_y$, where θ_x and θ_y are EVT thresholds of the variables X and Y , respectively.[26] Figure 3 shows the plots of the conditional probability P(q) = P($Y > F_Y^{-1}(q) \mid X > F_X^{-1}(q)$), i.e. the probability of EMP being in the upper tail given that the economic variable is in the tail, as a function of the percentile *q*, ranging from 0 to 1. If the two variables are asymptotically independent, the conditional probability on the *y*-axis goes to zero as the percentile *q* on the *x*-axis approaches one. However, if the variables are asymptotically dependent, the limit conditional probability does not approach zero when both variables move deeper into the tails (q→1).

[25] Note that for international reserves, the expected cell count is less than 5 in 25% of cells.
[26] For the negative relation, we multiply one of the two variables by -1.

TABLE 4

Tail Dependence of the EMP Index and Lagged Economic Signals

Variable	**Left tail (-)/ Right tail (+)**	**Downward Pressure Crisis on Thai Baht**		
		Uncon. Prob	**Con. Prob**	**Pearson (p value)**
International reserves (INR), lag 1	-	10.95	71.43	54.3736 (0.0000)
M2 (US$) to international reserves (MIR) , lag 1	+	10.95	35.59	42.9116 (0.0000)
Variable	**Left tail (-)/ Right tail (+)**	**Upward Pressure Crisis on Thai Baht**		
		Uncon. Prob	**Con. Prob**	**Pearson (p value)**
Nominal interest rate differential (ID), lag 8	+	8.68	16.94	15.3471 (0.0001)

Note: This table shows the unconditional probability of turmoil in the Thai baht market (Uncon. Prob), the conditional probability (Con. Prob) given the lagged economic indicator at the lag with the highest conditional probability (as shown in the first column), and Pearson's chi-squared test statistic with *p*-value in parentheses. A positive or negative sign indicates the right (+) or left (-) tail of the economic variable.

To give an idea, we first show two plots of the simulated data under the assumption of bivariate normal and bivariate Student-t (2 degree of freedoms) distributions with a correlation coefficient of 0.3593.[27] The left panel shows the case of asymptotic independence in which the conditional probability on the *y*-axis rapidly goes to zero as $q \to 1$. However, for the case of asymptotic dependence on the right panel, the conditional probability does not approach zero but lingers around a positive number in the limit. In this case, $\hat{\chi}$ = 0.429. There is similar evidence for the international reserves (INR), the ratio of money supply to international reserves (MIR), and the interest rate differential (ID) in Panels B and C. The plots deviate from the downward sloping diagonal and remain at around 0.4 for +EMP and around 0.3 for –EMP. These numbers are noteworthily similar to the limit probability $\hat{\chi}$ reported in Table 3.

The results presented in this subsection are consistent with the results from the asymmetric dependence tests shown in Tables 2 and 3. They reveal that the EVT-based approach can be applied for an individual country with a limited sample size. This practice is highly relevant for policy makers who are interested in country-specific factors underlying currency instability. The economic variables which are asymptotically dependent of the EMP index provide significant economic signals according to Pearson's chi-squared test results, and have a conditional probability approaching a positive number as shown in Figure 3. In the currency crisis literature, both international reserves (INR) and the ratio of money supply to international reserves (MIR) are used as indicators for signalling capital account problems, as seen for example, in the research of Kaminsky and Reinhart (1998, 1999) and Kaminsky (2006).[28] For the buying pressure, an increase in relative nominal yields (ID) makes a

[27] To simulate the data series, we use the means, standard deviations and correlation coefficient of the EMP index and international reserves INR.

[28] According to the literature, large declines in the international reserves may reveal abnormal capital outflows and reduce the credibility of the central bank in maintaining the exchange rate. As the ratio of money supply to international reserves measures the liabilities of the banking system which are backed up by

country more attractive for capital inflows. By and large, evidence points out that extreme movements in the Thai baht market are driven by capital flows.

V.5 Crisis Prediction Performance

Lastly, we compare the crisis prediction performance of economic indicators selected by the EVT-based approach and a standard probit model often used in the literature. However, since the EMP index does not indicate any crisis episode during the out-of-sample period (May 2011 to July 2013), we evaluate the in-sample crisis prediction performance.[29] To do so, we first create a crisis dummy by coding all months that are followed within 12 months by at least one downward pressure currency crisis by 1, and 0 otherwise. Then, we estimate a probit model using all economic indicators from Table 2. Insignificant variables are removed stepwise (5% sig. level). Based on the best-fitting model, the probability of currency crises rises following increases in domestic credit (DC) and currency overvaluation (QD1).[30]

Table 5 reports the unconditional crisis probability (Uncon. Prob of Crisis), the probability of currency crises given an economic signal (A), the probability of currency crises given that the economic indicator does not issue a signal (B), and the crisis prediction success (A – B). We examine the crisis prediction performance of the international reserves (INR) and the ratio of money supply to international reserves (MIR), which are the variables selected by the EVT-based approach, at the lag with the highest $\hat{\bar{\chi}}$. For domestic credit (DC) and currency overvaluation (QD1), which are the indicators selected by the probit model, we consider the lag with the highest conditional probability A. Note that an economic indicator is said to issue an economic signal when the variable is in the tail area, separated by the EVT threshold.

A good economic indicator for currency crises should have high conditional probability A, low conditional probability B, and hence high A – B. The international reserves (INR) and the ratio of money supply to international reserves (MIR) have the highest values of A – B among all the economic indicators used in the paper. While the currency overvaluation indicator (QD1) has higher conditional probability A than MIR, its conditional probability B is also higher than that of MIR. More importantly, the probit model excludes INR, which has the highest conditional probability A and prediction success A – B. In Figure 4, we show the strong relationship between the crisis prediction success A – B on the y-axis and the estimated extremal association measure $\hat{\bar{\chi}}$ on the x-axis, with a correlation estimate $r = 0.72$. Without maximising in-sample performance, such as a probit model that potentially overfits the data (see Kaminsky, 2006), the non-parametric EVT approach helps select economic indicators with high crisis prediction success.[31]

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international reserves, rapid growth in credit that raises the vulnerability of the banking system also lowers the credibility of the central bank in maintaining the value of domestic currency.

[29] In a cross-sectional study of 46 countries, Cumperayot and Kouwenberg (2013) show that economic variables which are asymptotically dependent with the crisis measure have better out-of-sample crisis prediction performance than a probit model. Moreover, for the EVT-based approach, there is a strong positive link between the in-sample and out-of-sample prediction performance. By using the probit model and the approach of Kaminsky, Lizondo and Reinhart (1998), the authors find a large discrepancy between good in-sample fits and out-of-sample results, as these approaches tend to overfit the data by maximising in-sample performance.

[30] To save space, details about the estimated probit model are available upon request.

[31] This finding coincides with a panel study of Cumperayot and Kouwenberg (2013).

TABLE 5
In-sample Crisis Prediction Performance

Variable	**Left tail (-)/ Right tail (+)**	**Downward Pressure Crisis on Thai Baht**			
		EMP			
		Uncon. Prob of Crisis	**Prob of Crisis, given Signal (A)**	**Prob of Crisis, given No Signal (B)**	**Crisis Prediction Success (A – B)**
International reserves (INR, lag 1)	-	10.95	71.43	8.82	62.61
M2 (US$) to international reserves (MIR, lag 1)	+	10.95	35.59	6.82	28.77
Domestic credit (DC, lag 1)	+	10.95	35.29	9.90	25.39
Currency misalignment (QD1, lag 12)	- (overvaluation)	10.95	37.50	10.42	27.08

Note: This table shows the unconditional probability of turmoil in the Thai baht market (Uncon. Prob of Crisis), the conditional probability given an economic signal (A), the conditional probability given no economic signal (B), and a measure of crisis prediction success (A-B). A positive or negative sign indicates a right (+) or left (-) tail of the economic variable.

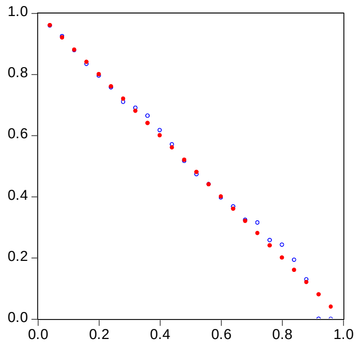
VI. CONCLUSION

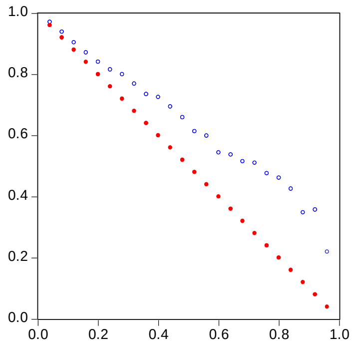
In this paper, by using Thai historical data, we study the tail characteristics and the linkage between the tails of the distributions of the currency instability measures, i.e. the exchange rate returns and the EMP index, and 21 economic fundamentals. The Hill (1975) estimator is used to estimate the tail index, while the simulation method of Jansen and de Vries (1991) is implemented for the threshold selection. The tail estimates indicate that the distributions of both currency instability measures and most economic variables exhibit heavy tails. In many cases, the tails are so fat such that the integral of the standard deviation is not bounded. Evidence thus illustrates that assuming a normal distribution for the variables tends to underestimate the probability of extreme events.

From the EVT cut-off points which divide observations in the centre range from observations in the tail areas, we then test asymptotic dependence between the currency instability measures and the lagged economic fundamentals using the asymmetric dependence tests of Poon et al. (2004). This provides a means of determining whether an economic variable issues a credible signal for instability in the Thai baht market. If the variables are asymptotically independent, the conditional probability of Thai baht instability given economic signals approaches zero in the limit as the value of the economic indicator becomes more extreme. From a crisis prevention perspective, the economic indicator is most likely a poor indicator of currency instability, as the relation between the variables vanishes for the extreme events that matter most.

Using the EMP index, we find that a large decline in the international reserves and a huge surge in the ratio of money supply to international reserves give significant signals one month before the extreme downward pressure in the Thai baht market with a limit probability of around 0.4. Furthermore, a drastic rise in the domestic yield relative to abroad is likely to be followed by extreme buying pressure between 7 to 10 months later with a limit probability of roughly 0.3. Interestingly, most of the economic variables which are often used as crisis signalling indicators are asymptotically independent with the currency instability measure. This implies that signals issued by these indicators are not reliable; as the economic variables behave more extremely, the likelihood of severe currency instability approaches zero.

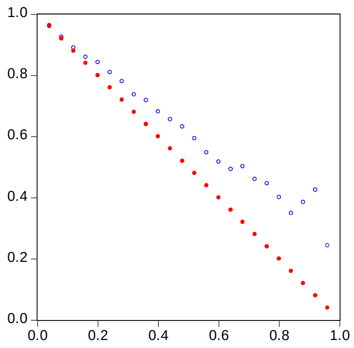
A) Simulated Plots



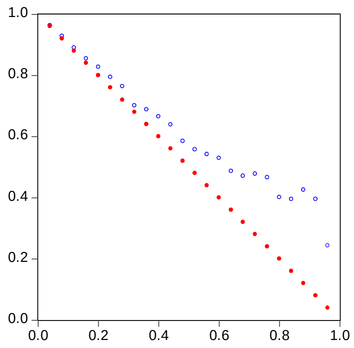


Correlated normal with ρ = 0.3593 Correlated Student-t 2df. with ρ = 0.3593

B) Downward Market Pressure (+EMP)

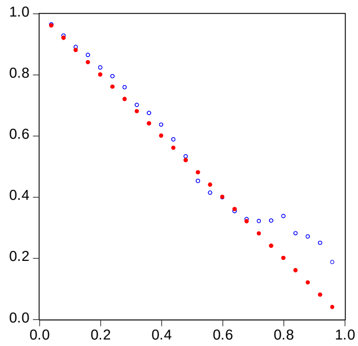


International Reserves
(-, lag 1)



Money Supply to
International Reserves (+, lag 1)

C) Upward Market Pressure (-EMP)



Interest Rate Differential
(+, lag 10)

Fig. 3. Plots of the conditional probability $P(q) = P(\,Y > F_Y^{-1}(q) \mid X > F_X^{-1}(q)\,)$, as $q \rightarrow 1$.
Note: The conditional probability of currency instability (on the *y*-axis) is plotted against the percentile *q* (on the *x*-axis).

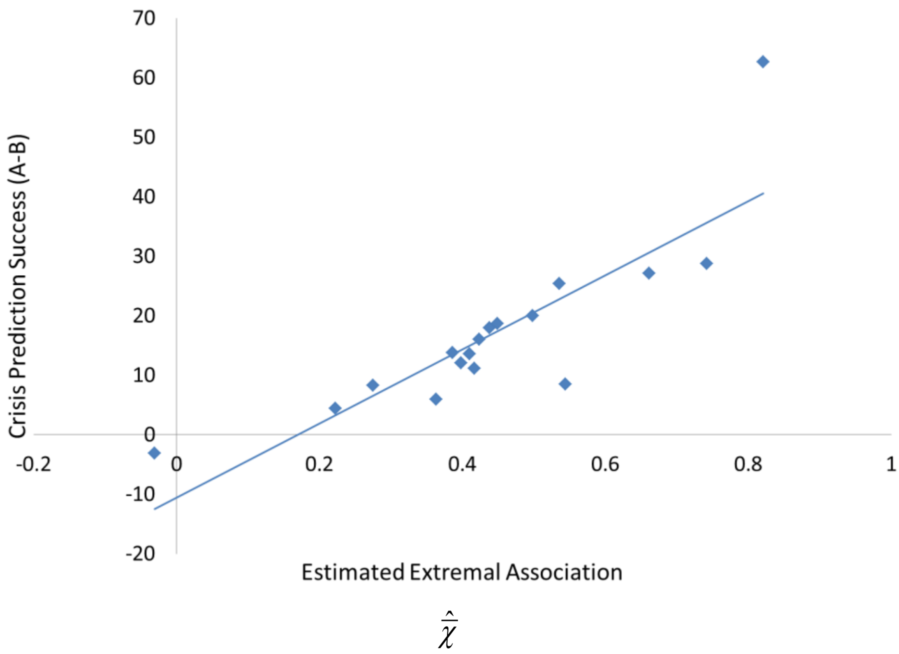


Fig. 4. Scatter plot of crisis prediction success (A – B) versus extremal association ($\hat{\chi}$)
Note: This figure shows a scatter plot of the in-sample crisis prediction performance A – B (on the y-axis), versus the estimated extremal association $\hat{\chi}$ (on the x-axis)

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APPENDIX: DATA SOURCE AND TIME SERIES CONSTRUCTION

The data are monthly observations from the IMF's International Financial Statistics (IFS). Observations are from January 1974 to July 2013, depending on availability. Descriptive statistics of the constructed variables are shown in Table A1 below.

For the two measures of currency instability, we use the exchange rate from IFS line: AE. The international reserves (in US$) are from IFS line: 1L.D. The monetary aggregate M2 is a sum of IFS lines: 34 and 35. For the short-term interest rate, we use the deposit interest rate (IFS line: 60L).

For the 21 economic indicators, all variables are monthly changes, except for the deviation of the real exchange rate from trend (QD), real interest rate (RI), and real interest rate differential (RID). These variables are measured in percentage points at month *t*. The data source and the construction of the series are explained below.

Domestic interest rate (I) and interest rate differential (ID):

If i_t (IFS code: 60L) is a monthly domestic interest rate (monthly rate = (IFS annual rate $\div 1200$)) at time *t* and i_t^* is a US monthly interest rate,

$$\Delta i_t = i_t - i_{t-1}, \text{------------------------} \text{ (I)}$$
$$\Delta i^*{}_t = i^*{}_t - i^*{}_{t-1},$$

$$\Delta \tilde{i}_t = \Delta i_t - \Delta i^*{}_t . \text{-------------------- (ID)}$$

International reserves in US dollars (INR):

If INR_t (IFS line: 1L.D) is the monthly international reserves (in US$) at time t, the monthly percentage change of international reserves at time t can be defined as

$$\Delta INR_t = \ln INR_t - \ln INR_{t-1} . \text{--- (INR)}$$

Money supply (MS):

If M_t (IFS code: 34+35) is money supply M2 (in national currency) at time t, its monthly growth rate is

$$\Delta M_t = \ln M_t - \ln M_{t-1} . \text{--------- (MS)}$$

Imports (IM):

If IM_t (IFS line: 71) is the monthly import value at time t, its monthly growth rate at time t is

$$\Delta IM_t = \ln IM_t - \ln IM_{t-1} . \text{------- (IM)}$$

Exports (EX):

If EX_t (IFS line: 70) is the monthly value of exports at time t, its monthly growth rate at time t is

$$\Delta EX_t = \ln EX_t - \ln EX_{t-1} . \text{------ (EX)}$$

Terms of trade (TOT_t):

Terms of trade at time t is defined as the unit value of exports (IFS line: 74) over the unit value of imports (IFS line: 75), i.e.

$$TOT_t = \frac{\text{unit value of exports at time t}}{\text{unit value of imports at time t}} .$$

The monthly rate of change of the terms of trade at time t is

$$\Delta TOT_t = \ln TOT_t - \ln TOT_{t-1} . \text{--- (TT)}$$

Inflation (INF) and inflation differential (INFD):

If p_t (IFS code: 64) is a price index at time t and p_t^* is the US price index, the monthly inflation rates are

$$\Delta p_t = \ln p_t - \ln p_{t-1} , \text{------------ (INF)}$$
$$\Delta p^*{}_t = \ln p^*{}_t - \ln p^*{}_{t-1} .$$

The inflation differential (INFD) is defined as

$$\Delta\tilde{p}_t = \Delta p_t - \Delta p^*{}_t.\text{-------------- (INFD)}$$

Domestic real interest rate (RI) and real interest rate differential (RID):

From the monthly deposit interest rate at time t i_t (IFS line: 60L divided by 1200) and the consumer price index at time t p_t (IFS line: 64), the real interest rate at time t r_t is derived from

$$r_t = i_t - \Delta p_{t+1},\text{-------------------- (RI)}$$

where $\Delta p_{t+1} = \ln p_{t+1} - \ln p_t$. Note that i_t, r_t and Δp_{t+1} are the levels of the monthly rates expressed in percentage points and cover the period from time *t* to *t+1*.

The domestic-foreign real interest rate differential at time *t* is

$$\tilde{r}_t = r_t - r^*{}_t,\text{--------------------- (RID)}$$

where $r^*{}_t$ is the US real interest rate.

M2 multiplier (MM):

M2 multiplier at time *t*, mm_t, is the ratio of M2 at time *t*, M_t (IFS lines: 34+35), to monetary base at time *t*, MB_t, (IFS line: 14), i.e.

$$mm_t = \frac{M_t}{MB_t}.$$

The monthly growth rate of the M2 multiplier at time *t* is then

$$\Delta mm_t = \ln mm_t - \ln mm_{t-1}.\text{----- (MM)}$$

Domestic credit (DC):

If DC_t is the domestic credit at time *t* (IFS line: 52), its monthly rate of change at time *t* is then

$$\Delta DC_t = \ln DC_t - \ln DC_{t-1}.\text{------ (DC)}$$

Real exchange rate (QC):

The real exchange rate q_t is derived from the nominal exchange rate s_t and the consumer price indices at home p_t and abroad $p^*{}_t$ (IFS line: 64). In equation,

$$q_t = \ln s_t + \ln p^*{}_t - \ln p_t.$$

Spot exchange rate at time *t*, denoted as s_t, is quoted as the price of a US dollar in terms of domestic currency (IFS line: AE), while p_t is the domestic consumer price index and $p^*{}_t$ is the US consumer price index.

The real exchange rate q_t measures the relative price of foreign products (in domestic currency) to the price of domestic products. A decline in the real exchange rate denotes a real appreciation. It implies that the domestic products become more expensive relative to the foreign products.

The monthly rate of change of the real exchange rate (QC) can be defined as

$$\Delta q_t = \ln q_t - \ln q_{t-1}. \text{------------- (QC)}$$

Currency misalignment (QD1, QD2 and QD3):

For QD1, the deviation of the real exchange rate from a deterministic time trend denoted as ε_t is derived from the ordinary least squared estimation of the real exchange rate q_t against a constant term c and a time trend $@trend$, i.e. $q_t = ls(c, @trend) + \varepsilon_t$. Therefore,

$$\varepsilon_t = q_t - ls(c, @trend),$$

where $ls(\bullet)$ is an ordinary least squared estimate.

The deviation of the real exchange rate from trend in percentage terms $q(trend)_t$ is

$$q(trend)_t = \frac{\varepsilon_t}{ls(c, @trend)}. \text{----- (QD1)}$$

For QD2, the ordinary least squared estimate $ls(\bullet)$ is replaced by a recursive least squared estimate (adding one observation at a time), while a moving average process (using a 60-month window) is used as a substitute for QD3.

Real commercial bank deposits (BD):

Real commercial bank deposits at time t B_t are commercial bank deposits (in national currency) at time *t* (IFS line: 24+25) divided by consumer price index at time t P_t (IFS line: 64). The monthly growth rate of the stock of bank deposits in real terms at time t $\Delta B_{t,1}$ is then

$$\Delta B_t = \ln B_t - \ln B_{t-1}. \text{------------ (BD)}$$

M2 to international reserves (MIR):

The ratio of money supply M2 to international reserves, $MINR_t$, is M2 in national currency (IFS line: 34+35) converted into US dollars (using IFS line: AE) divided by international reserves in US dollars (IFS line: 1L.D). The monthly growth rate is

$$\Delta MINR_t = \ln MINR_t - \ln MINR_{t-1}. \text{-- (MIR)}$$

International reserves to imports (IRIM):

The monthly growth rate of international reserves to imports, INR/IM, is

$$\Delta (INR/IM)_t = \Delta INR_t - \Delta IM_t. \text{-- (IRIM)}$$

Trade balance (TB):

If TB_t (IFS code: 70 –71) is the trade balance (exports minus imports) at time *t*, its monthly growth rate, ΔTB_t, is

$$\Delta TB_t = \frac{TB_t - TB_{t-1}}{TB_{t-1}}. \text{------------- (TB)}$$

TABLE A1

Descriptive Statistics

Variable	Mean	Median	Std. Dev.	Max	Min	Skew	Kurt.	Obs.
S	0.0009	0.0000	0.0255	0.2178	-0.2466	0.9882	43.8502	447
EMP	0.0000	0.0000	0.0017	0.0098	-0.0077	0.7787	8.1213	411
I	0.0000	0.0000	0.0012	0.0070	-0.0057	-0.0378	9.6604	411
ID	0.0000	0.0000	0.0012	0.0070	-0.0057	0.0790	9.5644	411
INR	0.0111	0.0127	0.0474	0.2694	-0.1884	-0.0293	8.0426	447
MS	0.0111	0.0100	0.0136	0.1144	-0.0554	1.6073	18.1089	446
IM	0.0098	0.0104	0.1048	0.3686	-0.3387	0.0457	3.1170	446
EX	0.0104	0.0112	0.1123	0.3245	-0.4830	-0.2057	3.8899	446
TT	-0.0016	-0.0008	0.0327	0.2794	-0.2000	0.5639	18.9714	439
INF	0.0040	0.0034	0.0069	0.0373	-0.0306	0.6541	7.4640	447
INFD	0.0005	0.0006	0.0060	0.0261	-0.0266	0.2080	6.1927	447
RI	0.0026	0.0027	0.0068	0.0329	-0.0256	-0.2715	5.0102	412
RID	0.0008	0.0010	0.0059	0.0266	-0.0292	-0.6490	6.3010	412
MM	0.0025	0.0066	0.0517	0.3421	-0.4208	-1.3066	22.2321	446
DC	0.0110	0.0110	0.0132	0.1333	-0.0523	1.2997	20.3960	446
QC	0.0004	-0.0009	0.0261	0.2124	-0.2522	0.7025	40.9089	446
QD1	0.0000	-0.0043	0.0354	0.1397	-0.0863	0.2221	3.0768	447
QD2	-0.0029	-0.0033	0.0351	0.1586	-0.0881	0.2934	3.8351	445
QD3	0.0068	-0.0027	0.0334	0.1866	-0.0574	1.1445	5.4458	388
BD	0.0074	0.0066	0.0131	0.0750	-0.0519	0.0720	6.7170	446
MIR	-0.0008	-0.0018	0.0539	0.2651	-0.4014	-0.5455	12.6675	446
IRIM	0.0012	0.0005	0.1159	0.4152	-0.3715	0.0069	3.3878	446
TB	0.4252	-0.0525	10.2709	194.4865	-63.4019	15.0138	292.6004	446

Note: This table shows the descriptive statistics of the variables used in this paper. In the table, S is the European term spot exchange rate; EMP is the exchange rate market pressure index; I is the domestic nominal interest rate; ID is the nominal interest rate differential; INR is the international reserves; MS is money supply (M2); IM is imports; EX is exports; TT is terms of trade; INF is the domestic price; INFD is the price differential; RI is the real interest rate; RID is the real interest rate differential; MM is money multiplier; DC is domestic credits; QC is the real exchange rate; QD1 is the deviation of the real exchange rate from the time trend using ordinary least squares; QD2 is the deviation of the real exchange rate from the time trend using recursive least squares (adding one observation at a time); QD3 is the deviation of the real exchange rate from its moving average (using a 60-month window); BD is the stock of real commercial bank deposits; MIR is the ratio of money supply to international reserves; IRIM is the ratio of international reserves to imports and TB is trade balance. Most variables are monthly rates of change and monthly changes for the nominal interest rate variables. For EMP, the variable is the exchange rate market pressure index measured at month *t*. For the deviation of the real exchange rate (QD), real interest rate (RI), and real interest rate differential (RID), the variables are measured in percentage points at month *t*.