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Exchange Market Pressure, Currency Crises and Monetary Policy: Evidence from Jamaica

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Abstract

This paper develops a measure of exchange market pressure (EMP) for Jamaica to gauge the severity of tensions in the foreign exchange market. Extreme Value Theory Analysis (EVA) is applied to three different weighting schemes popularly adopted in the literature for the construction of an EMP index. One of the well known uses of the index, determining a threshold level for signal of exchange market pressure, is also demonstrated. The paper identified several signals of exchange market pressure over the sample period.

Keywords: Currency crisis, Exchange market pressure, Exchange rate, Reserve, Extreme Value Theory,

EL Classification: E4, F31, F41,

[⊥] The views expressed in this paper are not necessarily those of the Bank of Jamaica.

1.0 Introduction

The value of the Jamaica Dollar vis-à-vis major foreign currencies, has come under severe pressure from time to time, since capital account liberalization in 1990. It is important for Jamaican policymakers to know when such pressure occurs and its intensity so that they can react decisively. The concept of exchange market pressure (EMP) and a framework to measure it were first introduced and developed by Girton and Roper (1977). Weymark (1997) further formalized this concept by indicating that the EMP on a currency is its excess supply on the foreign exchange market if policy makers would be "passive", that is, refrain from actions to offset that excess supply, where this positive (negative) excess supply is expressed in the relative appreciation (depreciation) required to remove it. Consequently, in a floating exchange rate regime, EMP coincides with the observed depreciation, whereas in all other regimes EMP is the depreciation-equivalent of excess supply in the counterfactual of a passive policy maker. This is the definition of EMP employed in the literature, either implicitly or explicitly.

As the counterfactual case is not observed, EMP is unobservable. However, if there is pressure, policy variables are generally set to eliminate it, possibly together with a change in the exchange rate. These observations give the opportunity to measure EMP in an indirect way. The literature has derived such a measure within a monetary model of exchange rate determination. To date the most general EMP measure is a weighted average of three components, namely the exchange rate change, interest rate change and the change in reserves.

Investigating the EMP is relevant for at least two reasons. The first concerns monetary policy. Many developing countries, like Jamaica, or emerging markets such as China and some EU member states pursue some kind of exchange rate management, mostly in relation to the value of the US dollar.[1] Even in countries classified as having de facto freely floating rates, which for example pursue an inflation target, sometimes intentionally try to influence the exchange rate. Such policies can be optimal in theoretical models, for instance, to limit exchange rate pass-through in prices or, if pass-through is weak, to reduce real exchange rate fluctuations that would otherwise distort

[1] The IMF (2007) de facto classification of exchange rate regimes shows that 52% of 148 currencies have some sort of peg, and 32% have a managed float with no predetermined path for the exchange rate. See Husain *et al*. (2005) for further details.

consumption allocations (see Calvo and Reinhart, 2002; Devereux and Engel, 2007). Consequently, for monetary policy makers it is relevant to gauge how much pressure they can expect on their own currency as a result of contagion.

EMP is also important for analyses that use the concept to examine other interesting phenomena. Some authors use EMP to estimate regional vulnerability to crises, while others use it to examine whether fundamentals are strong (see Mody and Taylor, 2007; Van Poeck *et al*., 2007). IMF (2007) employs EMP to study adequate policy responses to capital flows, and the recently developed IMF financial stress index for emerging economies contains EMP as one out of five indicators. The idea of pressure is also relevant for country credit ratings.

In addition to constructing EMP index, the present study defines a threshold level to reflect the pressure in the market and explore for its determinants in Jamaica. The outline of the study is as follows. Section 2 presents the literature review regarding analysis and construction of exchange market pressure index. The definition, methodology and the selection of the threshold level for EMP is discussed in section 3. This section also presents the functional form of determinants of EMP index and an extreme value theoretical approach to determining the threshold value. The key results and main findings are presented in section 4. The paper ends with a summary and some policy implications in section 5.

2.0 Literature Review

Exchange market pressure is usually reflected in changes of official holdings of foreign exchange reserves and the nominal exchange rate. Under a complete fixed exchange rate regime, the central bank has to defend the committed parity with, in principle, unlimited purchases or sales of foreign exchange in case of excess demand for or excess supply of domestic currency. Under a pure floating exchange rate regime, the central bank has no such commitment and the exchange rate is totally free to absorb any change in demand and/or supply of the home currency. However, neither completely fixed nor pure floating regimes exist worldwide. The fact that changes in the exchange rate and in foreign exchange reserves often occur together indicates that monetary authorities tend to employ intermediate exchange rate systems. Under an intermediate regime, the excess demand or supply pressure that the home currency faces is usually relieved by a combination of both official reserve changes and exchange rate changes. Therefore, how a currency's EMP can be measured under the intermediate exchange rate regime is of great importance and has attracted increasing attention from policy makers, researchers, academics and international economists.

As mentioned in the previous section, the EMP concept was first put forward by Girton and Roper (1977). They construct an EMP index that is the sum of international reserve changes and exchange rate changes. Other economists have conducted empirical tests on the EMP index to identify the effect of monetary policy (Kim, 1985; Burdekin and Burkett, 1990; Yunus, 2005).[2] The simple framework of Girton and Roper (1977) was further developed in a small open economy model setting (Boyer, 1978; Roper and Turnovsky, 1980). In this framework, a policy reaction function of the central bank is defined and the EMP index construction improved.[3] Under the framework of Roper and Turnovsky (1980), although the EMP index is still a linear combination of international reserve changes and exchange rate changes, the weights of the two components are no longer identical.

A seminal study on the EMP index was undertaken by Weymark (1995) in which the author modifies the limitations of previous research (e.g. Girton and Roper, 1977; Roper and Turnovsky, 1980) and constructs an IS-LM-AS-type small open economy model under the price stickiness assumption. She also introduces a conversion factor parameter into the EMP index construction and estimates it. This parameter represents the relative weight of the exchange rate changes to the intervention changes (represented by international reserve changes) in the EMP index. Many empirical analyses and estimations (e.g. Kohlscheen, 2000; Zhu, 2003; Stavarek, 2007) have since been conducted following the work of Weymark (1997) to estimate the EMP index using variations of the conversion factor parameter.

Weymark (1995) and Eichengreen *et al*. (1996) extended the monetary model of Girton and Roper (1977) to improve the EMP measure. In particular, they employ a weighted average of the exchange rate, interest rate change and change in reserves. In the

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[2] Yunus (2005) offers a more comprehensive survey of empirical research on EMP under the Girton and Roper (1977) framework.

[3] See Roper and Turnovsky (1980) for the specifications of the policy reaction function.

extensive EMP empirical literature, all studies have used (a variant of) this EMP measure. The EMP index and the parameters in Weymark (1995) and Eichengreen *et al*. (1996), for example, are defined and estimated on the basis of structural models of exchange rate determination theory. Therefore, the EMP index is called a model-dependent index and the approach to estimate the index is called a model-dependent approach. Some economists (e.g. Eichengreen *et al*., 1995) have criticized this approach. They hold that structural models of exchange rate determination are difficult to explain and fail to predict the exchange rate movements in the short run. They further highlight the fact that recent research has confirmed that the random walk outperforms more sophisticated structural models of exchange rate determination for forecasts up to one year (Krugman and Obstfeld, 2003). To avoid such a shortcoming, Eichengreen *et al*. (1995) and Sachs *et al*. (1996) put forward a model-independent EMP index that is a linear combination of the interest differential, the percentage changes of both bilateral exchange rates and foreign exchange reserves.[4] The general method of computing the EMP index is outlined below (see equation 1).

$$EMP_t = \Delta s_t + w_1 \Delta i_t + w_2 \Delta r_t, \qquad (1)$$

where s is the exchange rate in natural logarithm, i_t is the home interest rate, such that $\Delta i_i = i_t - i_t^*$, and r_t is the international reserves adjusted by base money (B), such that $\Delta r_t = (R_t - R_{t-1})/B_{t-1}$. If the index is below zero, the home currency is facing appreciation pressure; otherwise, the currency is facing depreciation pressure. The weights of interest rate changes and reserve changes are w_1 and w_2, respectively.

There is much criticism regarding the model-dependent EMP index and its analytical approach (Eichengreen *et al*., 1995; Sachs *et al*., 1996). However, the model-independent EMP index is not perfect either. The question remains whether the empirical estimations of the EMP index based on the two approaches are consistent with each other? Economists have paid much attention to this question. Stavarek (2007), for example, finds that the two approaches are not compatible and will lead to different

[4] Generally speaking, the way that a central bank intervenes in the foreign exchange market can be classified into two methods: direct intervention and indirect intervention. The former refers to the purchase and sales of foreign exchange by the central bank where as the latter refers to interest rate adjustments and consequently, the bank can relieve some of the exchange market pressure.

estimations of the EMP index. A set of researchers have employed econometric techniques, such as logit, probit and VAR models, to estimate the probability, size and timing of speculative attacks and currency devaluations. For instance, Frankel and Rose (1996), Eichengreen *et al*.(1995, 1996), Berg and Pattillo (1999) and Kumar *et al*. (2003) apply parametric techniques, such as probit models, to pooled panel data. Some studies estimate structural theoretical models. For example, Connolly and Taylor (1984), Blanco and Garber (1986), Goldberg (1994), and Flood and Marion (1997) empirically test the balance of payments problems that occur due to inconsistent macroeconomic policies of fixing the exchange rate and persistent money-financed fiscal deficits.

Furthermore, the work of another set of economists, dubbed the "signaling approach", searches for common crisis factors and uses these indicators to build an early warning system that predicts the likelihood of currency crises out of sample. The pioneering work in this area by Kaminsky *et al*. (1998) investigates whether signals issued by economic indicators are followed by currency crises within the next 24 months. The study by Kaminsky *et al*. (1998) covers a large set of indicators inspired by the theoretical and empirical literature on EMP. The authors define currency crises occurring when the EMP index, a weighted average of monthly percentage depreciations in the exchange rate and monthly percentage declines in international reserves, exceeds its mean by three standard deviations. Indicators send out warning signals whenever they move beyond their thresholds, which are selected to minimize the in-sample noise-to-signal ratio of the indicators.[5]

For this study, it is important to immediately underscore that a currency crisis in the context of an exchange market pressure is not only defined as capturing instances of successful attacks, i.e., when a depreciation of the currency occurs, but as well as instances of unsuccessful attacks (pressure rebuffed by loss in reserves and/or rise in interest rates).

The appropriate definition of a currency crisis is undoubtedly very crucial here. The literature has usually defined currency crisis occurring when the EMP exceeds a certain threshold. The use of the threshold in defining currency crisis has, however,

[5] The signaling model by Kaminsky et al. (1998) has been accompanied by a series of related works, such as Goldstein (1998), Goldstein *et al*. (2000), Kaminsky (2006), and Kaminsky and Reinhart (1999)

largely been of an arbitrary process. Frankel and Rose (1996) for example, apply exchange rate depreciations of 25.0 per cent or more over a one year period to identify currency crashes. But this is not necessarily the optimal approach because, as the authors point out, though this method identifies currency crashes, it does not necessarily pick up currency crises. Other papers have also adopted 1, 2 or even more standard deviations as their choice of threshold.

A currency crisis in the context of this paper takes a slightly broader concept that results from speculative pressures that are placed on a currency. Sometimes the speculative attack is successful, in which case, there are likely to be large exchange rate depreciations. But at other times, the central bank is able to ward off the speculators. In this case, the exchange rate may remain fixed and losses in international reserves, increases in domestic interest rates, and/or the imposition of capital controls may occur. Thus, for the purpose of better understanding and identifying the origins of crises, it is more useful to devise a broader definition to capture currency crises and periods of economic ‘stress’ rather than simply currency crashes.

There are two main approaches in the empirical EMP literature: model-based and model-independent EMP indices. The former is introduced by the seminal paper by Girton and Roper (1977) to describe the composite behaviour of exchange rates and international reserves. They build up a monetary model, where the dependent variable is the EMP index, defined as a simple sum of the percentage depreciation of the currency and the negative change in the stock of international reserves scaled by base money. In particular, Girton and Roper (1977) constructed EMP variables by averaging changes in the exchange rate with international reserve gains and losses.[6] This framework is based on the consideration that an extreme speculative depreciation pressure can be neutralized by the monetary authorities either by letting the exchange rate fall or by selling foreign exchange reserves. This approach has been often used in the empirical literature. However, although derived from a model, the EMP index in the Girton-Roper approach is actually independent of model estimates, since by definition both components of the index contribute equally to its value. This point was subject to critique in a series of

[6] This variable was constructed to test some of the propositions of the monetary model of the exchange rate in the case of Canada, which at the time followed a system of managed floating exchange rates.

papers by Weymark (1995, 1997). The author shares arguments of Girton and Roper (1977) on the necessary components of an EMP index, but introduces and estimates a parameter (conversion factor) representing the relative weight for exchange rate changes and foreign flows in the EMP measure.

Several empirical papers aimed at predicting currency crises (eg. the literature on early warning indicators) do not concentrate on a specific model for the exchange market pressure variable. Instead, they use a simpler measure, defined originally by Eichengreen (1995), which is fully model-independent, the second approach in the empirical EMP literature. Their EMP index is a weighted sum of exchange rate changes, international reserve changes, and interest rate changes. However, contrary to Weymark's approach, the weights are calculated from sample variances of the three components with no need to estimate any model. This simplicity made the EMP index widely used as the dependent variable in currency crisis models, but equally widely criticized by theoreticians for its strong *a priori* assumptions about the weighting scheme. In the interest of measuring currency crises, Eichengreen *et al*. (1996) modify the Girton and Roper (1977) definition of EMP by adding a third term: relative interest rate changes. Interest rates are often manipulated to counter capital flows and moderate speculative attacks. Hence, the authors make a case for including relative interest rate movements to fully capture periods of currency crisis as they provide information on speculative pressure on a currency. Subsequently, Eichengreen *et al*. (1996) define periods of exchange market crisis as taking place during periods of time for which 'unusually large' values of EMP result. This methodology for identifying currency crises has been followed, in principle, by Sachs *et al*. (1996); Kaminsky et al. (1998) and Kaminsky and Reinhart (1998).[7]

3.0 The Exchange Market Pressure Index

3.1 Developments of the research

This is the first research to do an in-depth estimation and examination of an EMP index for Jamaica.[8] The study uses monthly data from January 2000 to August 2010 to

[7] Actually, in these papers interest rate differential were not included because the countries examined contained too many developing countries for which market interest rates were unavailable or unreliable.
[8] Previous study in this area for Jamaica was done in the form of a policy note in 2003 by the Research and Financial Stability Departments at the Bank of Jamaica.

conduct the empirical estimations. The paper mostly resembles the signaling approach and shares the idea that an effective warning system should be built based on a broad variety of economic indicators. This is due to the fact that currency crises are usually preceded by a broad range of economic problems that vary over time and across countries. Following Kaminsky *et al*. (1998), the research examines economic fundamentals selected from the theoretical literature. However, instead of using the existing approaches for building an early warning system from these indicators, the aim here is to construct an early warning system for currency crises by explicitly taking into account and analyzing the fat tail statistical properties of the economic variables and the exchange rate.

The early warning system for currency crises developed by Kaminsky *et al*. (1998) relies on the standard deviation to set a threshold for identifying currency crises. The currency crisis episodes thus identified are subsequently used to find "signal" thresholds for the fundamental economic indicators that minimize the in-sample noise-to-signal ratio. Extreme value theory (EVT), on the other hand, allows for the identification of extreme value thresholds for the currency crisis measures and economic indicators using non-parametric techniques, without making prior assumptions about the shape of the unknown population distribution, allowing for both normal and non-normal distributions.[9] Inappropriately imposing the assumption of normality on a fat-tailed distribution will result in underestimation of the probability of extreme events.

According to Pozo and Amuedo-Dorantes (2003), indentifying currency crises using extreme value theory is a good alternative to the conventional method. Employing the currency crisis definition of Eichengreen *et al*. (1996), Pozo and Amuedo-Dorantes (2003) show that the extreme value method signals more episodes of speculative pressure and more accurately indicates actual crisis incidences than the conventional standard deviation approach. Besides, evidence in the paper shows that for series with relatively thin tails, such as the EMP indices for selected developed countries, the extreme value method provides similar results as the conventional method. However, the extreme value approach is shown to be more appropriate for series with heavier tails, i.e. from

[9] The "*x* times the standard deviation" method applied by Kaminsky et al. (1998) and others implicitly assumes a normal distribution.

developing and emerging market economies, including the EMP indices of many Asian and Latin American countries.

Pozo and Amuedo-Dorantes (2003) demonstrate the usefulness of univariate EVT for identifying currency crises in sample without aiming to improve or build an early warning system. The contribution of this paper is to apply EVT to select economic fundamentals as indicators for currency turmoil and to predict the conditional crisis probability, given signals issued by these indicators. Our main tool for assessing economic fundamentals as indicators for future currency crises is the concept of asymptotic dependence.

When an EMP index and an economic fundamental variable are asymptotically independent, the conditional currency crisis probability approaches zero in the limit as it moves deeper into the tail and events become more extreme. The limiting conditional crisis probability is only positive when the pair of variables is asymptotically dependent. Asymptotic dependence in the tail area, analyzed with multivariate extreme value theory, can be completely different from regular dependence over the entire domain of the variables. For example, Sibuya (1960) shows that any pair of variables that follows a bi-variate normal distribution with Pearson correlation coefficient $\rho < 1$ is *asymptotically independent*, even though the variables are dependent in the usual sense for all $\rho \neq 0$.

Following Poon *et al*. (2004), the study assesses asymptotic dependence with two non-parametric statistics, derived from EVT. It is hypothesized that those economic fundamentals that are asymptotically independent with the currency crisis measure will not provide good predictions of future currency crises. The paper investigates this empirically using historical data from January 2000 to August 2010 for out-of-sample tests. It also describes how EVT can be used to assess the conditional probability of a currency crisis given signals issued by lagged economic fundamentals. An interesting feature of this approach is that the conditional crisis probability can also be assessed for crisis events and economic signals beyond the range observed in the historical data.

Although there is limited or no research that applies EVT to model the relationships between macroeconomic variables and currency crisis measures, there are studies that apply EVT to analyze extreme dependence in financial markets.[10] It has been demonstrated that variables with a Pearson correlation coefficient of zero may still exhibit dependency in the tail areas (Embrechts *et al*., 2002 and de Vries, 2005).[11] Hartmann *et al*. (2004) shows that the joint probabilities of both stock market and bond market returns are estimated inaccurately under the assumption of multivariate normality. Given the fact that foreign exchange rates and many macro-economic fundamentals have non-normal distributions with fat tails, this paper aims to improve the early warning system of Kaminsky *et al*. (1998) by applying extreme value methods.

3.2 The Exchange Market Pressure Index Intuition

By definition, the general EMP outlined above (see equation1) is the relative counterfactual exchange rate change. Therefore, it is not surprising that the components in the EMP measure are in relative terms and that Δs_t enters directly. First, regarding the components in the EMP index, the underlying intuition for their inclusion is provided. First, regarding Δs_t, suppose that the exchange rate is floating, so that $i_t = i_t^*$ and $R_t - R_{t-1} = 0$, then, $EMP_t = \Delta s_t$. Furthermore, any *ex ante* excess supply will lead to a change in the exchange rate, and for this, it is irrelevant at what level the exchange rate is, so s_t cannot be an EMP component by itself. Moreover, if a shock at time *t* makes the economy jump from one steady-state equilibrium to another, the exchange rate moves from its initial equilibrium to the new equilibrium value, so that the exchange rate relative to its (contemporaneous) equilibrium level is zero in both cases. Because there was *ex ante* excess supply on the foreign exchange market due to the shock, taking s_t relative to its equilibrium level is apparently also inappropriate as an EMP component. The appropriate transformation is the first difference of s_t.

Second, consider the interest rate component, $i_t - i_t^*$. The presence of the interest rate in the EMP expression is due to the prominent role interest rates play in the set of policy instruments. Suppose there is a multi-period episode of high pressure (such as a

[10] Longin and Solnik (2001), Embrechts *et al*. (2002), Bradley and Taqqu (2003), Poon *et al*. (2004), Hartmann *et al*. (2004), and de Vries (2005), among others.

[11] The Pearson correlation measure gives little weight to tail events and is thus prone to inadequately capture the interdependency in the tail areas when the variables are non-normally distributed.

speculative attack) and the central bank successfully withstands that pressure by adjusting interest rates, then Δi_t would signal the adjustments. The last component in the EMP index is international reserves. Here it is obvious that the reference value is zero, so that $R_t - R_{t-1}$ naturally enters directly in the EMP measure.

A rise in the value of the index indicates an increased pressure and vice versa. Unlike the values of a price index, the resulting values of the EMP index have no intuitive meaning. The percentage change in the EMP index between two points in time can be estimated. The resulting number may suggest that the pressure in the exchange market has increased or decreased by that amount. But this would not have the same meaning as saying that inflation was 5.0 per cent, for example, over a certain period. A price index measures the change in one variable, the ‘price’ of a bundle of goods. The EMP index on the other hand, is a composite index which incorporates changes in three different variables of which two are prices and one is a quantity.

Furthermore, note that researchers define large positive values of the EMP index to identify periods of crises and ignore negative extreme values. That is, values of EMP that result, for example, from large appreciations of a currency or large increases in international reserves are not deemed crisis periods. Though countries may suffer from the ramifications of large appreciation pressures, these ‘crises’ are deemed fundamentally different from exchange rate crises that result in depreciation pressure. Hence, in defining extreme values to identify currency crisis periods, researchers exclusively focus on extreme positive values for EMP.

But which yardstick should be used to determine largeness? Usually the standard deviation of the EMP series is used. In Kaminsky *et al*. (1998) and Kaminsky and Reinhart (1998), any EMP value that is 3 standard deviations (S.D.) away from the country’s own mean value for EMP is used to define a crisis period. Eichengreen *et al*. (1996) define EMPs greater than 1.5 S.D. over the mean (where the mean and standard deviation are for the entire sample) as crisis periods. The more relevant question, however, is how to weight the three components of the index of speculative pressure? This paper explores three recent studies on EMP indices, which are then used to examine the case for Jamaica.

3.3 EMP Index: Eichengreen, Rose and Wyplosz (1995, 1996)

The research begins by estimating Eichengreen *et al*. (1996) to construct the EMP index as a weighted average of exchange rate changes, international reserve changes and interest rate changes.[12] The exchange market pressure index of Eichengreen *et al*. (1996) is expressed as:

$$EMP_t = \left[a\frac{\Delta e_t}{e_t} \right] - \left[b\left(\frac{\Delta rm_t}{rm_t} - \frac{\Delta rm_t^*}{rm_t^*} \right) \right] + [c\Delta(i_t - i_t^*)] \qquad (2)$$

where EMP_t indicates the EMP index for Jamaica in period *t*; e_t represents the exchange rate of US$1 at time *t*; rm_t is the ratio of international foreign reserves to money stock or base money and rm_t^* represents the ratio of international foreign reserves to money stock or base money for the US (the reference country) at time *t*. The weights *a*, *b* and *c*, attached to each component are used to equalize the volatilities of each of the three EMP components and are defined as the inverse of the standard deviation of each of the individual series.

Eichengreen *et al*. (1996) define crisis as taking place when EMP is greater in value than 1.5 S.D. of the entire sample's average value. This definition of identifying crisis periods is maintained for the other two methods outlined below (see equations 3 and 4). Formally:

Crisis = 1 if $EMP_t > \mu_{EMP} + 1.5\sigma_{EMP}$

Crisis = 0 otherwise,

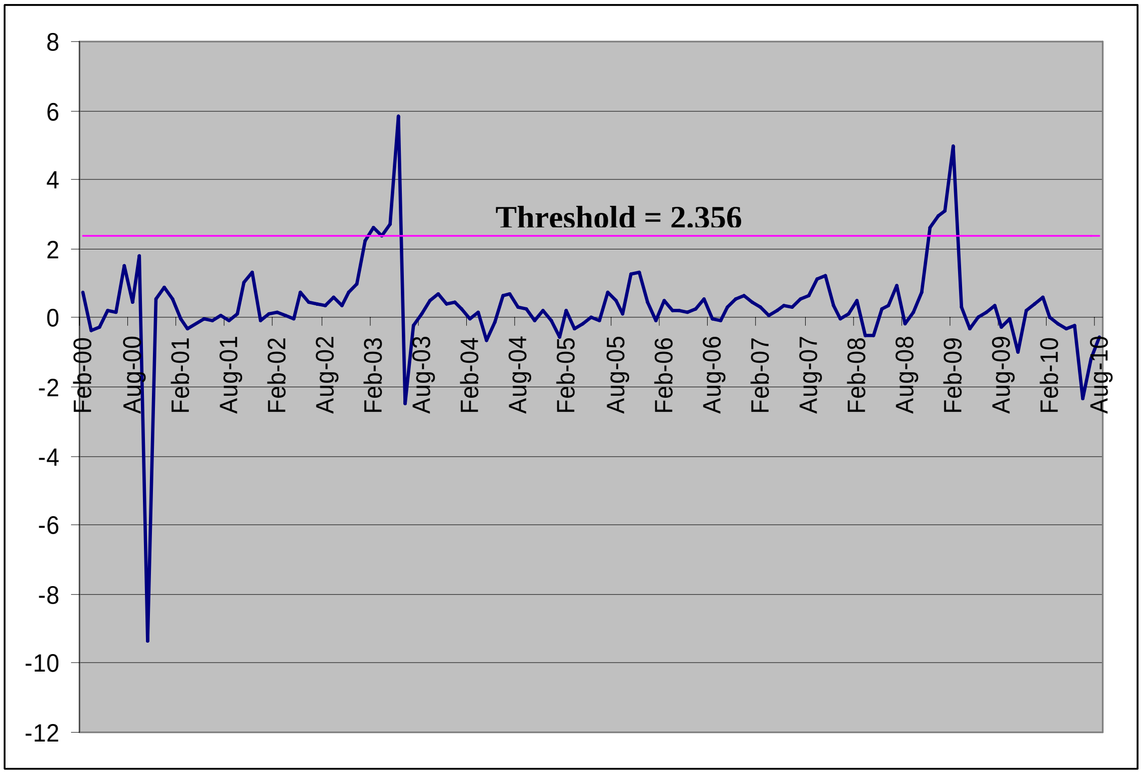
where μ_{EMP} and σ_{EMP} denote the respective mean and the standard deviation for the entire sample of the EMP index.

The paper reproduces the EMP index for Jamaica using the Eichengreen *et al*. (1996) methodology. It then use this series to identify periods of intense speculative pressure – crises periods. The study identifies seven months during the sample period where there were intense speculative pressures or crises periods based on the Eichengreen *et al*. (1996) methodology (see Figure 1). The crisis months, identified by the Eichengreen methodology, are: February 2003, April 2003, May 2003, November 2008, December 2008, January 2009, and February 2009. This process is also done using the

[12] All data employed are of monthly frequency covering the period January 2000 to August 2010.

Sachs *et al*. (1996) and the Kaminsky *et al*. (1998, 1999) discussed below (see sections 3.4 and 3.5)

Figure 1. Exchange market pressure index – Eichengreen method



3.4 Sachs, Tornell and Velasco (1996)

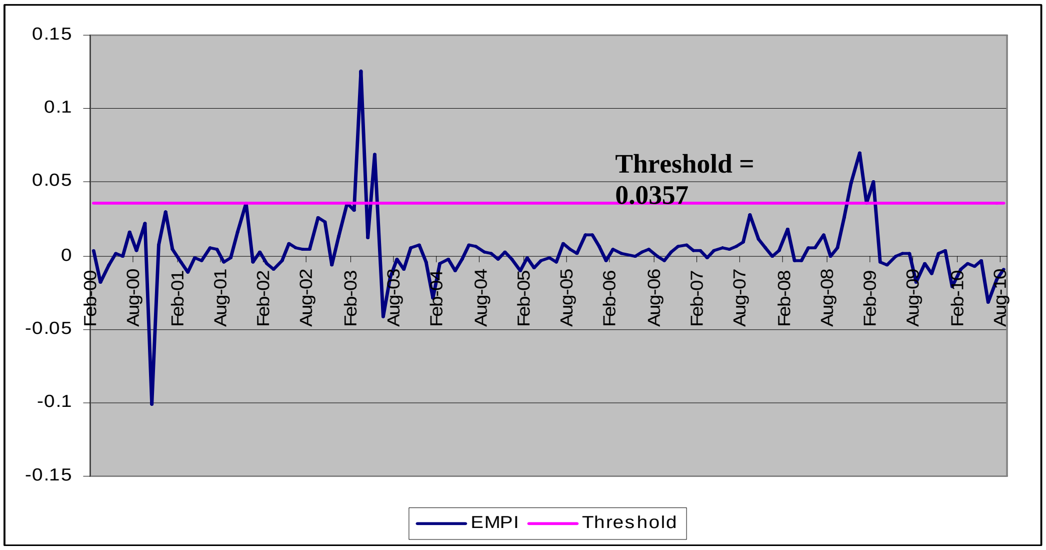
The second method employed to compute the exchange market pressure index is that of Sachs *et al*. (1996). This methodology is similar in nature to the Eichengreen *et al*. (1996) model, except for the weighting scheme. The EMP index is expressed as follows:

$$EMP_t = \left[\frac{1/\sigma_e}{\left(\left(1/\sigma_e\right)+\left(1/\sigma_r\right)+\left(1/\sigma_i\right)\right)}\right]\frac{\Delta e_t}{e_t} - \left(\frac{1/\sigma_r}{\left(\left(1/\sigma_e\right)+\left(1/\sigma_r\right)+\left(1/\sigma_i\right)\right)}\right)\frac{\Delta r_t}{r_t} + \left[\frac{1/\sigma_i}{\left(\left(1/\sigma_e\right)+\left(1/\sigma_r\right)+\left(1/\sigma_i\right)\right)}\right]\Delta i_t \quad (3)$$

where EMP_t is again the exchange rate market pressure index in period *t*; e_t is the Jamaica Dollar per U.S. dollar in period *t*; r_t represents foreign reserves in period *t*; σ_e is the standard deviation of the rate of change in the exchange rate $\left(\frac{\Delta e_t}{e_t}\right)$; σ_r represents the standard deviation of the rate of change in reserves $\left(\frac{\Delta r_t}{r_t}\right)$; and σ_i is the standard deviation of the change in the nominal interest rate Δi_t.

Using the Sachs method, the study identifies seven months during the sample period where there were intense speculative pressures or crises periods (see Figure 2). This result is similar to that which obtained from the Eichengreen method, at least in terms of the number of crisis periods identified. However, there is a slight variation in the actual months where intense speculative pressures or crises periods were experienced. Crisis periods identified, using the Sachs method, are: November 2001, March 2003; May 2003; November 2008, December 2008; January 2009; February 2009.

Figure 2. Exchange market pressure index – Sachs method



3.5 Kaminsky, Lizondo and Reinhart (1998, 1999)

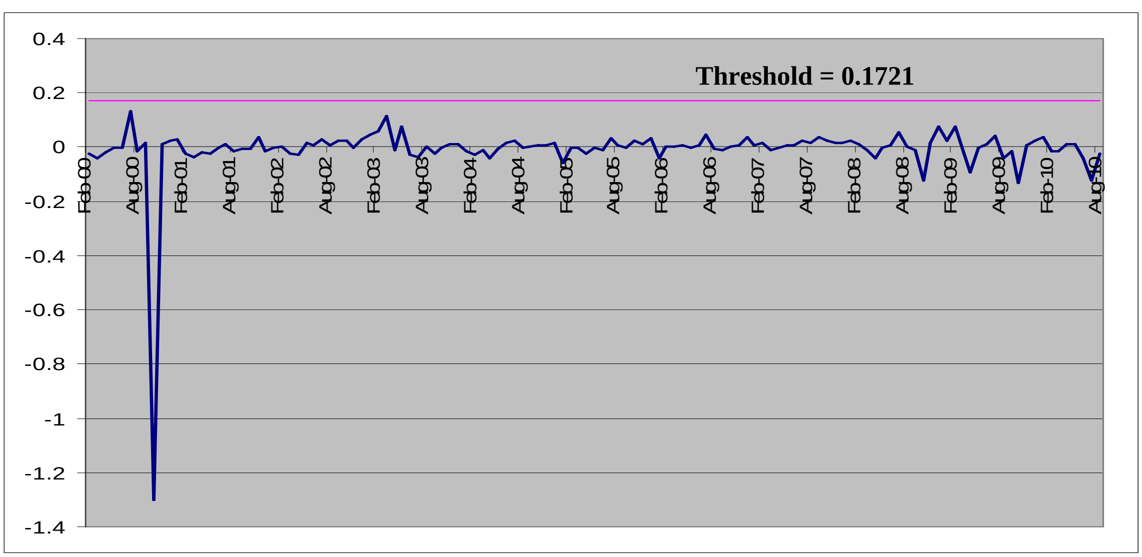
The third method of estimating the EMP index is that of Kaminsky et al. (1998, 1999). The EMP index is expressed as follows:

$$EMPI_t = \frac{\Delta e_t}{e_t} - \frac{\sigma_e}{\sigma_r}\frac{\Delta r_t}{r_t} + \frac{\sigma_e}{\sigma_i}\Delta i_t \qquad (4)$$

where the variables are defined the same as in Sachs *et al*. (1996). The differentiating factors between the definitions of the EMPI are the weights. In this case, note that the rate of change in the exchange rate $\left(\frac{\Delta e_t}{e_t}\right)$ is unweighted; the rate of change in reserves $\left(\frac{\Delta r_t}{r_t}\right)$ is weighted by the ratio of the S.D. of the rate of change in the exchange rate σ_e and the S.D. of the rate of change in the reserves σ_r; while the change in nominal interest rate is weighted by the ratio of the S.D. of the rate of change in the exchange rate σ_e and the S.D. in the change in interest rate σ_i.

Interestingly, the Kaminsky *et al*. (1998, 1999) method of estimating the EMP index did not signal any crisis period over the sample January 2000 to August 2008. This is an interesting result and has significant implications for researchers and policy makers which are discussed later on in this paper (see section 5).

Figure 3. Exchange market pressure index – Kaminsky method



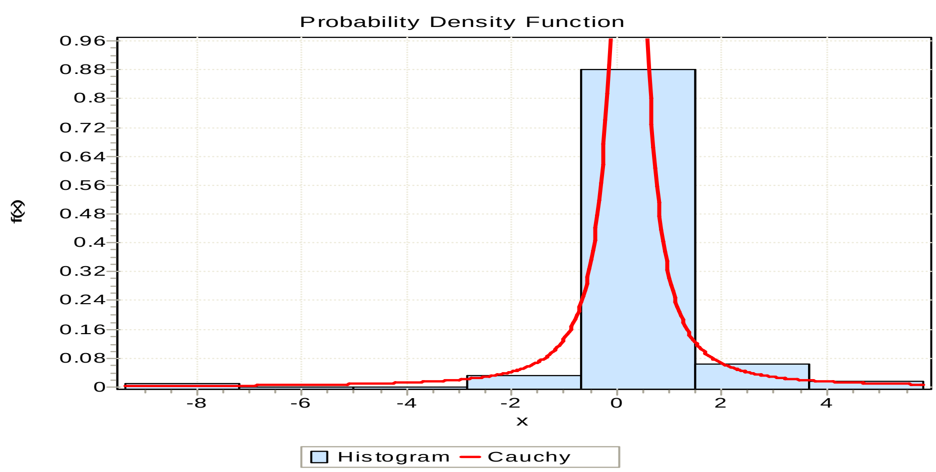
4.0 Extreme Value Theory

4.1 The empirical distribution of the EMP

When defining crises as periods for an EMP index more than 1.5 S.D. above the mean, there is an underlying assumption about the distribution of the series – i.e., that the series is characterized by well behaved standard normal probability density functions. This assumption is at variance with a few studies in the literature characterizing the probability distribution functions of speculative price series. The series, in practice, appear to be better characterized as 'fat-tailed' or leptokurtic and possibly lacking finite second moments (see Figure 4a, 5a, and 6a). Furthermore, the Q-Q plot of the EMP index for each method, confirms that all series fit a Cauchy type distribution (see Figures 4b, 5b, and 6b).[13]

If such is the case, then the three methodologies used for identifying extreme EMP values maybe inappropriate, since sample standard deviation cannot truly capture the dispersion in the respective series. The EMP index series is, of course, not strictly speaking price series. Nonetheless, given the components of EMP index and the 'speculative nature' of the individual component series, it seems logical to suspect that EMP index may share some of the same empirical characteristics of speculative price series.

Figure 4a. Frequency distribution of EMPI and corresponding hypothetical normal probability density function – using Eichengreen method



[13] This distribution is found to be most suitable for the EMP indices based on a statistical software (Mathwave – Easyfit 5.4). The Cauchy distribution is symmetric and bell shaped, like the normal distribution, but its 'tails' do not taper off nearly as quickly as those of the normal distribution.

Figure 4b. QQ plot of the EMP index using Eichengreen method.

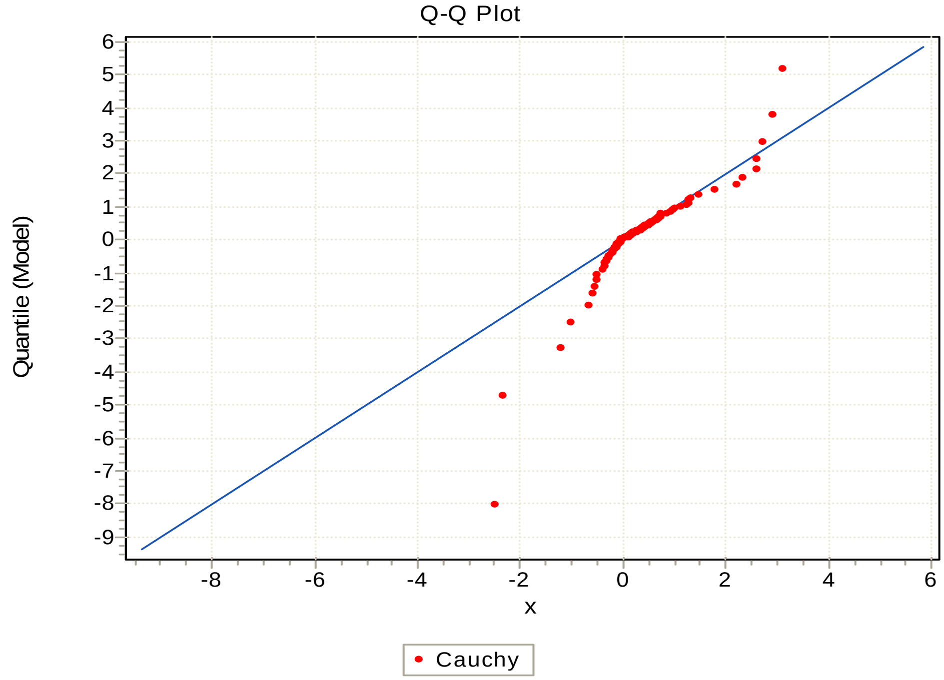


Figure 5a. Frequency distribution of EMPI and corresponding hypothetical normal probability density function – using Sachs method

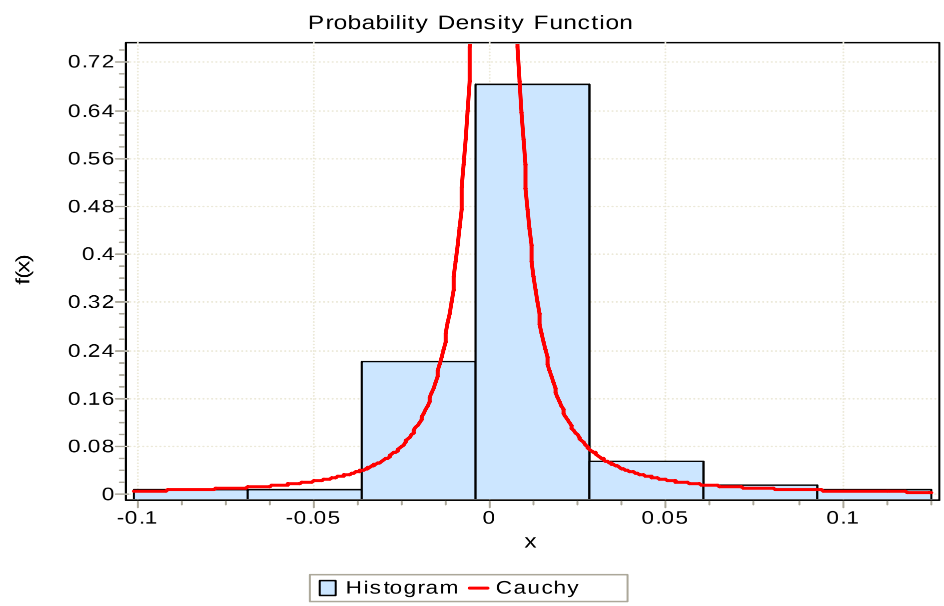


Figure 5b. QQ plot of the EMP index using Sachs method.

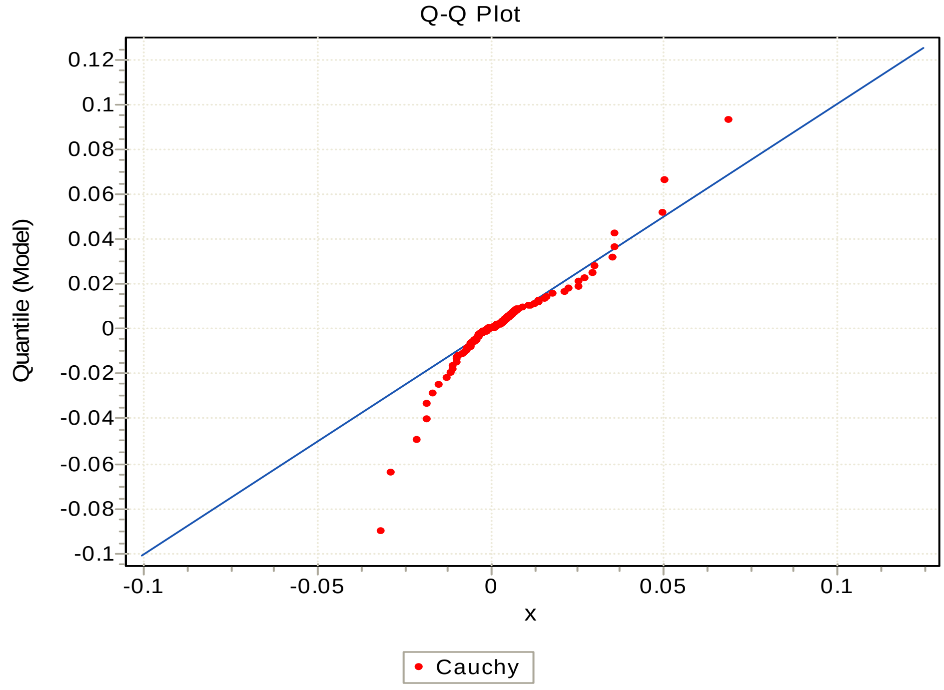


Figure 6a. Frequency distribution of EMPI and corresponding hypothetical normal probability density function – using Kaminsky method

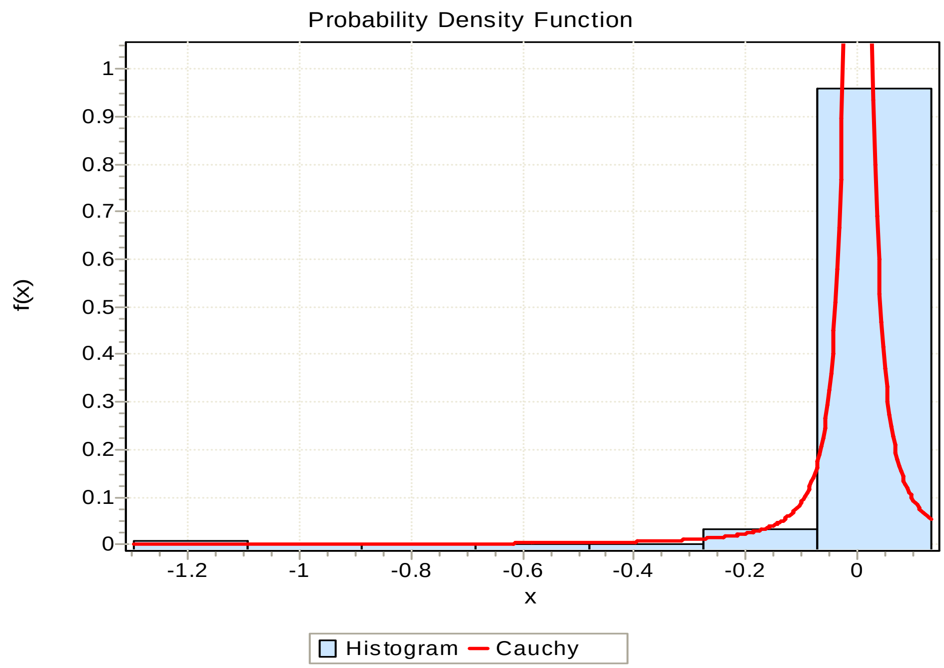
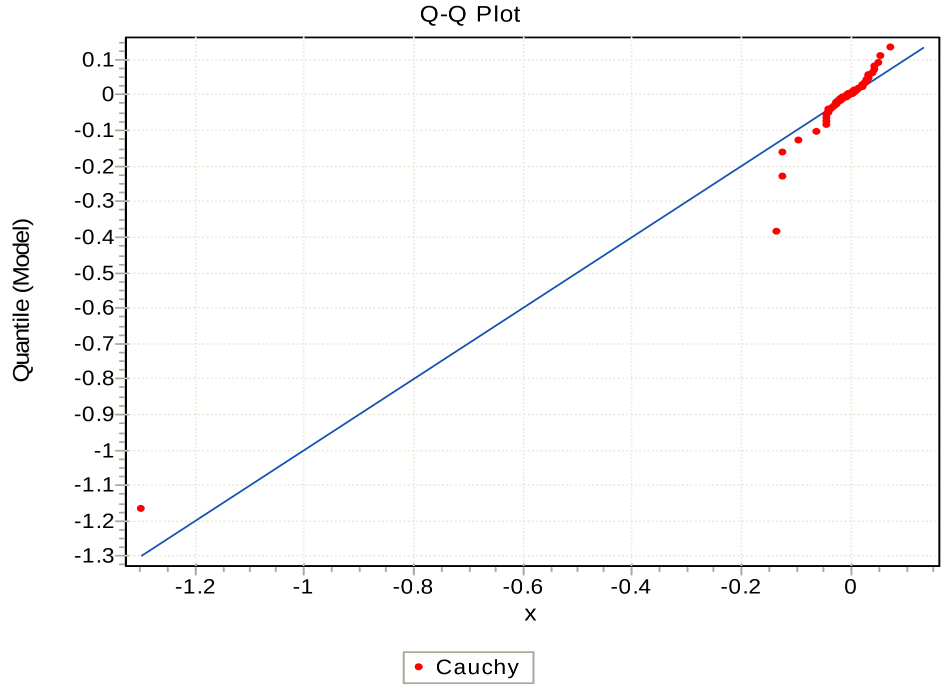


Figure 6b. QQ plot of the EMP index using Kaminsky method.



4.2 Extreme Value Analysis

Since exchange rate returns appear to be characterized by fat tails and volatility clustering, several alternative distributional models have been posited to describe exchange rate series including the sum-Stable, Student-*t*, and ARCH processes.[14] Though several researchers have attempted to distinguish between these alternative specifications for exchange rate movements, they typically have not been successful at doing so. In large part, this is because the parameters estimated (the characteristic exponent and the degrees of freedom) to distinguish among these models are not nested (Koedijk *et al*., 1990).

However, there does appear to be a promising approach to identifying the distribution to which exchange rate returns belong. Koedjik *et al*. (1990, 1992) and Hols and de Vries (1991) suggest using extremal analysis. With extremal analysis, the value for the tail parameter (α) can be estimated and inferences about the distribution from

[14] For examples of papers suggesting these various distributions for exchange rate movements see Rogalski and Vinso (1978); Boothe and Glassman (1987); Akgiray *et al*. (1988); Baillie and Bollerslev (1989); Hsieh (1989).

which the data came can be made, because the different distributions are nested in the value taken on by the tail parameter. The tail parameter takes on values between 0 and 2 when the distribution is in the domain of attraction of a stable law, while it takes on values of 2 and above in the Student-*t* and specific ARCH cases. Hence, by obtaining an estimate for α, the distribution that characterizes the data can be determined. This approach is employed to characterize the distribution of EMP. But, it is also shown that, in taking this approach, the study is able to identify extreme observations and thereby derive a new methodology for identifying currency crisis periods.

Koedijk *et al*. (1992) point out that Akgiray *et al*. (1988) were the first to truly distinguish between the Student-*t* and stable distributions by estimating the shape of the tail using extremal analysis. However, Koedijk *et al*. (1992) argue that one can better distinguish between the different types of distributions using nonparametric methods in place of the maximum likelihood estimation (MLE) approach used earlier by Akgiray *et al*. (1988). In particular, they show that the MLE method is less efficient and produces higher standard errors, which complicates differentiating among distributions. Consequently, this current paper follows Koedijk *et al*. (1992) and uses the Hill estimator to estimate the value of α for the EMP variable.

As mentioned earlier, the tail index estimator proposed by Huisman *et al*. (2001) which is unbiased in small sample cases is applied to alleviate the issues arising from the estimation methodologies outlined above. The Huisman *et al*. (2001) starts with the commonly used Hill (1975) estimator where it is assumed that there is a sample of n positive independent observations drawn from some unknown fat-tailed distribution.[15] Let the parameter γ be the tail-index of the distribution and $x(i)$ be the i th-order statistic such that $x(i-1) \leq x(i)$ for $i = 2,\ldots,n$. Suppose that k observations from the right tail are included in the estimate, then Hill (1975) proposes the following estimator for γ:

$$\gamma(k) = \frac{1}{k}\sum_{j=1}^{k}\{(\ln x_{n-j+1}) - (\ln x_{n-k})\} \quad (5)$$

where k is the pre-specified number of tail observations. Naturally, the choice of k is crucial to obtain an unbiased estimate of the tail-index.

[15] The Hill estimator requires the use of stationary and serially uncorrelated data.

Huisman *et al*. (2001) show that for a general class of distribution functions the asymptotic expected value of the conventional Hill estimator tends to be biased and increasing monotonically with *k*. Similarly, the asymptotic variance of the Hill estimator to be proportional to $\left(\frac{1}{k}\right)$. Generally, this problem will only be resolved when the sample size goes to infinity for given *k*. Huisman *et al*. (2001) introduce an estimator that overcomes the problem of the need to select a "single" optimal *k* in small sample observations. The authors propose that for values of *k* smaller than some threshold value K, the bias of the conventional Hill estimate of γ increases almost linearly in *k* and can be approximated by:

$$\frac{1}{\alpha} = \gamma(k) = \gamma + \beta k + \varepsilon(k)\,, \qquad k = 1,2,\ldots,\mathrm{K} \qquad (6)$$

where $\varepsilon(k)$ is a disturbance term. Huisman *et al*. (2001) also show that the modified Hill estimator is quite robust with the choice of K to be around $\left(\frac{n}{2}\right)$. Accordingly, for the empirics, the study computes $\gamma(k)$ for a range of values for *k* from 1 to K.[16]

To estimate equation (5), Huisman *et al*. (2001) adopt Weighted Least Squares (WLS) instead of Ordinary Least Squares (OLS), to deal with the potential heteroskedasticity in the error term, $\varepsilon(k)$, of equation (6). The weight has $\left(\sqrt{1},\sqrt{2},\ldots,\sqrt{k}\right)$ as diagonal elements and zeros elsewhere. The estimate of γ from the WLS regression is an approximately unbiased estimate of the tail-index.

The one trick to the procedure outlined in equation (5), is to choose the appropriate value for *k*, which determines the number of observations used to estimate $\gamma(k)$. The study uses the procedure suggested by Loretan and Phillips (1994), employed by Kalb *et al*. (1996), and strongly encouraged by Embrechts *et al*. (1997). The research estimated $\gamma(k)$ using a range of values for *m* and chose that *m*-value where $\gamma(k)$ is stable. That is, the range for which $\gamma(k)$ remains relatively stable is identified and the

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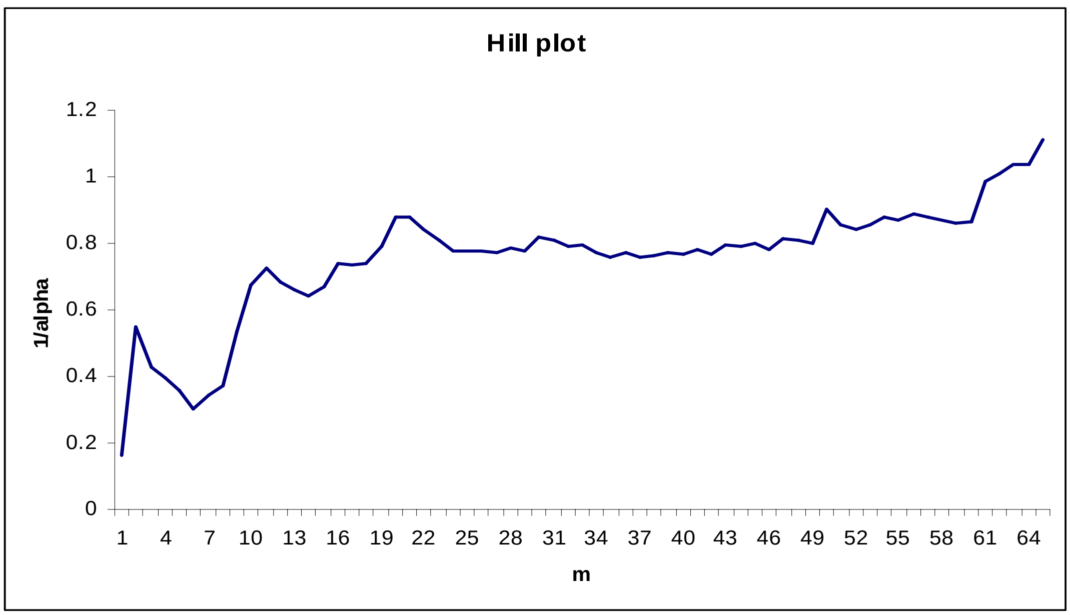
[16] Where K is approximately equal to $\left(\frac{n}{2}\right)$.

corresponding m-value is chosen to obtain the estimate for α. Embrechts et al. (1997) refer to the resulting series of $\gamma(k)$ as a Hill plot.

Estimates for $\gamma(k)$ are devised for each EMP index estimation method and for different values of m ranging from 1 to 65 and are graphed as a Hill plot outlined below (see Figures 7, 8, 9). Note that for low values of m, all tail observations are not being employed; therefore α estimates will have too large a variance. By contrast, using a value for m that is too high will lead to a bias in the estimate from 'contaminating' the sample with observations from the center of the distribution.[17] From the Hill plots (see Figures 7, 8) it appears that $\gamma(k)$ first stabilizes at m equaling about 25, for both the EMP indices computed using the Eichengreen and Sachs methods. While using the EMP index computed from the Kaminsky method, it appears that $\gamma(k)$ first stabilizes at m~13 (see Figure 9).

Figure 7. Hill plot using Eichengreen method



[17] See Kalb *et al*. (1996) for a discussion of this efficiency-bias trade-off.

Figure 8. Hill plot using Sachs method

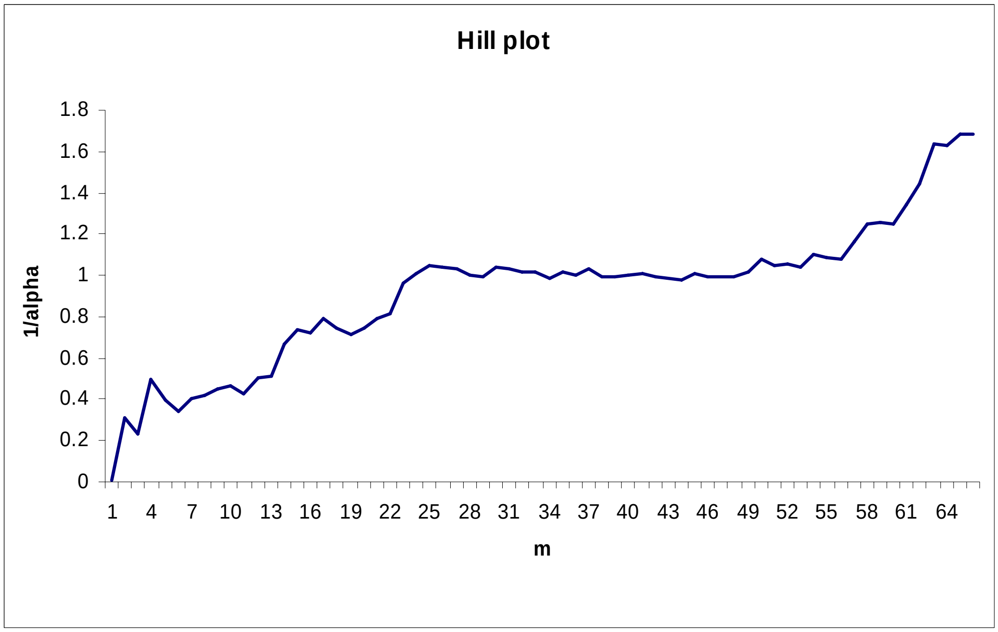
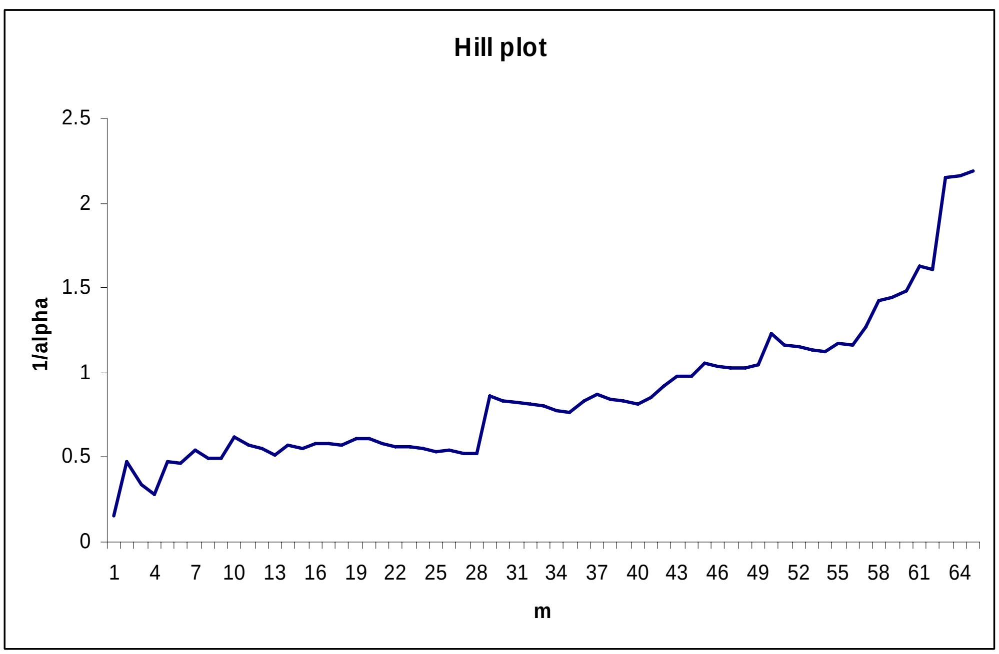


Figure 9. Hill plot using Kaminsky method



However, one problem still remains with this procedure. Though a procedure exists for selecting *m* in a statistically optimal way (see Danielson *et al*., 2001), it is only appropriate for large samples. The sample employed in this study is made up of monthly observations with an n that is too small to employ such a method. A recursive least squares methodology is used to verify that the stabilization in the behaviour of $\hat{\gamma}(k)$ and its associated m have been properly identified. These are plotted against a bandwidth of plus and minus two standard errors for all estimation of EMP index. Examination of the recursive residuals in relation to the standard errors verifies that there was a structural break around m equaling approximately 25 using both the Eichengreen and Sachs method to compute the EMP index, justifying the identification of the stabilization of $\hat{\gamma}(k)$ at these m's (see Figures 10, 11). Further justification is that $\hat{\gamma}(k)$ stabilizes when m is approximately 13 for estimation of the EMP index using the Kaminsky method (see Figure 12).

Figure 10. Recursive residuals using Eichengreen

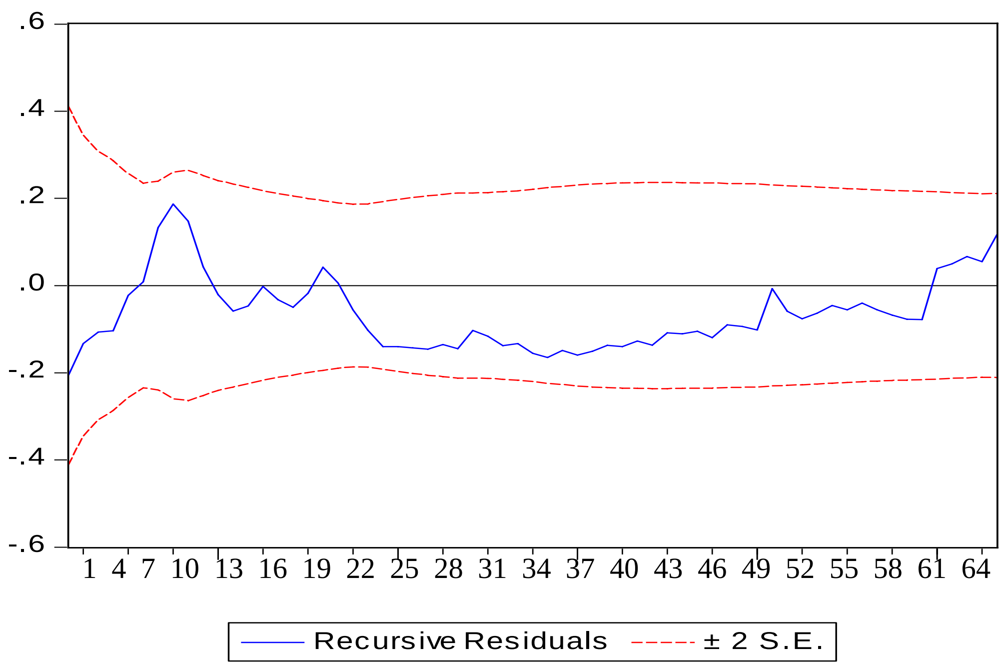


Figure 11. Recursive residuals using Sachs

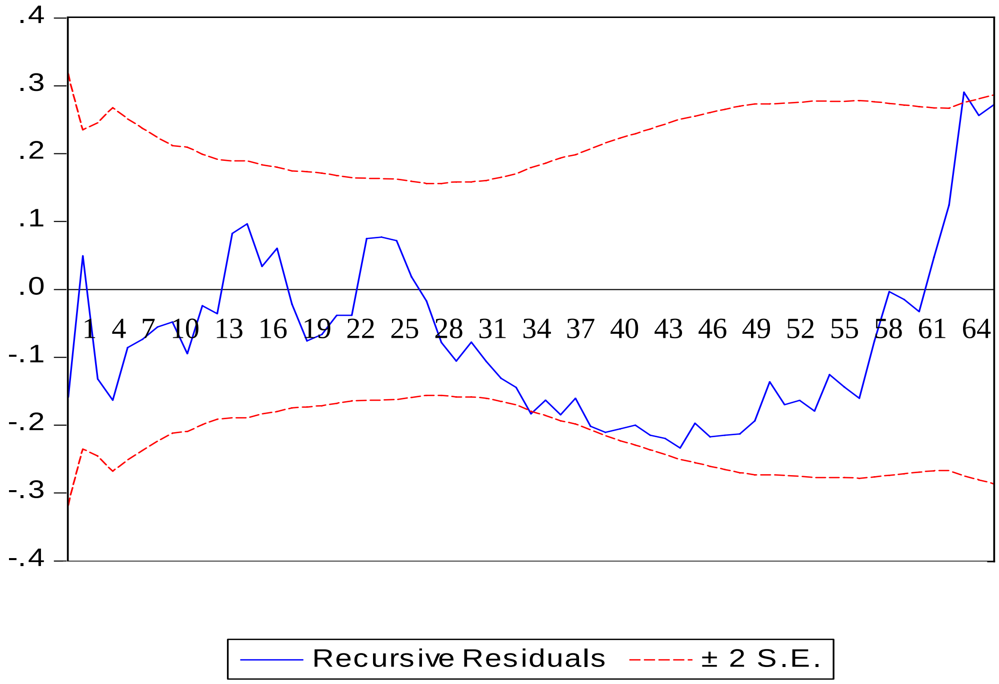
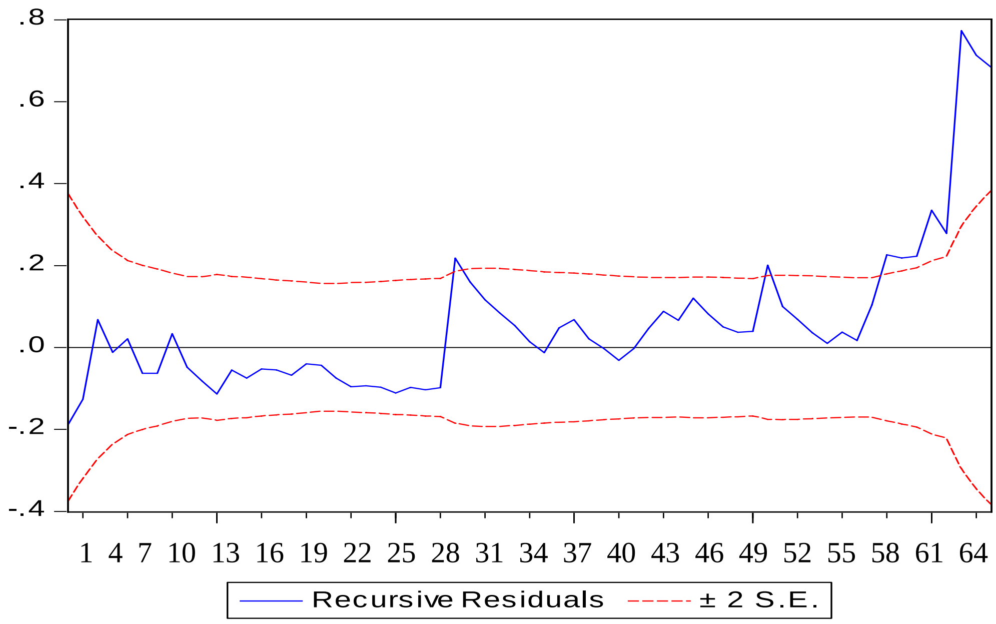


Figure 12. Recursive residuals using Kaminsky



The value obtained for α by the Eichengreen and Sachs methods described above are 1.29 and 0.95, respectively (see Table 1). Note that the estimated value for α is less than 2, suggesting that the distribution for EMP is in the domain of attraction of a stable law. Similarly, the estimated value for α is less than 2 (approximately 1.95) when the EMP index using the Kaminsky method is used. To ascertain the statistical significance of these results, a 95.0 per cent confidence interval is constructed for the respective α's (see Table 1).[18] The result that none of the confidence intervals does not contain the value 2, suggests that the distribution of the EMP indices belongs to the domain of attraction of the stable law.

Table. 1 Parameter values for the Hill estimators[a]

	n	m	$\hat{\gamma}$	$\hat{\alpha}$	95% CI for α	m/n
Eichengreen	126	25	0.775	1.29	[1.346, 1.607]	0.198
Sachs	126	25	1.051	0.95	[1.167, 1.408]	0.198
Kaminsky	126	13	0.512	1.95	[1.299, 1.601]	0.103

[a] *n* represents the number of observations; *m* represents the number of tail observations; *m/n* is the incidence of crisis.

4.2 Identifying crisis periods using extreme value theory

In this section, following Embrechts *et al*. (1997) periods of currency crisis are identified by finding those values of EMP that are "extreme values". The approach is to simply identify the 'tail' observations. If the tail distribution can be identified, then extreme observations can be determined.

It turns out that this is easily done because in finding the estimate for α, the (right) tail observations according to EVT would have been identified. In the case of estimating the EMP index using both the Eichengreen and Sachs methods, the top 25 order-statistics ($X_{(102)}$ to $X_{(126)}$) are the extreme observations (indicating 25 crisis periods over the sample) and hence constitute the 'tail' observations for EMP. The procedure for identifying currency crisis periods is to determine which of the $X_{(102)}$ to $X_{(126)}$ matches the EMP series. Similarly, in the case of estimating the EMP index using the Kaminsky

[18] Not that $(\hat{\gamma}(k) - \gamma(k))m^{1/2}$ is asymptotically normal with mean zero and variance γ^2

method, the top 13 order-statistics ($X_{(114)}$ to $X_{(126)}$) are the extreme 'tail' observations for the EMP (indicating 13 crisis periods over the sample).

The identified crises months are outlined and arranged in chronological order, for each of the EMP index estimation methodology employed (see Table 2). For comparison purposes, the crisis episodes identified using the Eichengreen method is listed in the first two columns (with both the threshold and extremal results). Several conclusions emerge from comparing the results outlined (see Table 2). First, the Eichengreen *et al*. (1996) threshold only picks the most severe (and recognized) currency crisis that hit Jamaica (the 2003 and 2008 crises). Second, the extremal method picks up the most severe crises as well, for all three EMP index estimation method used. Third, in addition to the most severe crises, the extremal analysis identifies several periods when the Jamaican foreign exchange market was 'stressed' that are not picked up by the respective threshold methods.

Table 2. Crisis observations using extremal and the three threshold methodologies.

Eichengreen		Sachs		Kaminsky	
Threshold	Extremal	Threshold	Extremal	Threshold	Extremal
	2000: 2, 7, 9, 12		2000: 7, 9, 12		2000: 7
	2001: 10, 11	2001: 11	2001: 10, 11		2001: 11
	2002: 5, 11, 12		2002: 5, 9, 10, 12		
2003: 2, 4, 5	2003: 1, 2, 3, 4, 5, 7, 10, 11	2003: 3, 5	2003: 1, 2, 4, 5		2003: 1, 2, 3, 5
	2005: 7, 10, 11		2005: 10, 11		2006: 7
	2007: 9, 10		2007: 8, 7, 10		2007: 9
2008: 11, 12	2008: 7, 10, 11, 12	2008: 11, 12	2008: 2, 7, 10, 11, 12		2008: 7, 12
2009: 1, 2	2009: 1, 2	2009: 1, 2	2009: 1, 2		2009: 2, 7
					2010: 1

5.0 Summary and policy implications

Despite the lack of interpretive intuition, the EMP index serves as a useful measure of the conditions in Jamaica's foreign exchange market. With it, the conditions of the foreign exchange market should be monitored on a regular basis for policy decisions. Furthermore, given the magnitudes of both the economic and the social costs of any financial crises, constructing an accurate early warning signal indicator should undoubtedly be an important research focus. From this study, two key points emerge and are worth noting for future efforts at formulating crisis indicators.

First, it is highly recommended that a range of indices is adopted to ensure the robustness and conclusiveness of the results. The empirical exercise finds variation in the three sets of EMP indices. Based alone on total mean and standard deviation, using the extremal methodology, the Eichengreen indicator suggests that the Jamaican foreign exchange market was most 'stressed' in May 2003. In contrast, the other two indicators suggest that the foreign exchange market was most stressed in the latter part of the sample (February 2009 using Sachs method, and January 2010 using Kaminsky method).

Second, the results of the paper also show that by employing the EVT approach which takes into account the basic statistical properties of an EMP index, the conventional threshold approach of identifying crisis periods was substantially improved, regardless of the standard weighting schemes used in the construction of the EMP index. This statistical rationale stems from several seminal findings that any financial price series do not typically exhibit distributions that are normal, and that this crucial piece of information about speculative price series is, usually, assumed 'away' or takes on lesser importance compared to other issues, eg., reflected in the search for additional econometric methods, in the literature on the early warning signals (EWS) of currency crisis.

In this paper, the performance of the extremal value method is compared with the threshold method to identify currency crises. It is evident from the results that the extremal value method is more sensitive than the threshold method for identifying crisis as it signals more periods of speculative pressure. According to the extremal method, 25 months of crisis are identified, while using the Eichengreen method, for example, only 6 months of crisis are identified. Furthermore, the crisis incidence appears more sensible in the extremal method case. While the Eichengreen method, for example, suggests the incidence of crisis is approximately 5.5 per cent (7 out of 126 months of crisis). However, for the extremal method, the incidence of crisis is about 20.0 per cent (25 out of 126 months of crisis).

As is the case for all other approaches used to identify currency crisis periods, the approach employed in this study may not provide an unambiguous standard that can be used to verify the *actual* occurrence of a currency crisis. There is no formal definition of currency crisis derived from theory and multilateral organizations do not systematically categorize crisis countries. Hence, there is no way to 'grade' the accuracy of these multiple approaches. Nonetheless, the extremal approach appears to dominate the Eichengreen-type approaches on statistical grounds by avoiding *a priori* assumptions regarding the underlying distribution of the EMP series. This is particularly important considering the existing uncertainty regarding the true distribution of speculative price series. In addition to the statistical rationale for employing extreme value theory, the results conform better with anecdotal evidence concerning the propensity of currency crises in Jamaica.

In sum, the study employed a promising method to distinguish currency crises, that is, extreme value theory, which may help to better measure speculative pressure in Jamaica's foreign exchange market and understand the determinants, development and contagion channels surrounding currency crises. Based on the actual occurrence of 'stressed' periods in Jamaica's foreign exchange market, the Eichengreen method using EVT appears more superior. The challenge for researchers and policymakers is that different crisis episodes appear to have different causes. Consequently, the usefulness of the methodology employed in this research for predicting currency 'crises' in Jamaica remains to be tested.

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